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AIR CUSHION CRASH RESCUE VEHICLE (ACCRV)

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This technical report has been reviewed and is approved for publication.

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Current USAF crash rescue vehicles have been designed to operate on the roads, ramps, taxiways, and runways which make up a typical airbase. These vehicles perform quite well on these surfaces, however, due to their use of tires, with inflation pressures of 60-70 psi, these vehicles have only limited capability to operate over rough terrain and soft surfaces. Unfortunately, many aircraft accidents occur off of hard surfaces, in areas inaccessible to current crash rescue vehicles. To increase the mobility over these surfaces, an Air Cushion Crash Rescue Vehicle (ACCRV) has been designed by integrating a retractable air cushion system with a crash rescue vehicle. This report summarizes the preliminary design and trade-offs associated with the ACCRV program.

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1.0 INTRODUCTION

This report describes the results of an Air Force program to develop an Air Cushion Crash Rescue Vehicle (ACCRV) conducted, under contract FY1456-85-02073. This contract included three phases of study; Concept Design, described in the Phase 1 R&D Design Evaluation Report, No. 7646-927001 (Ref. 1), a preliminary vehicle design described in Phase II Preliminary Design Report, No. 7646-927003 (Ref. 9), and a third phase effort, consisting of design and fabrication of a scaled Dynamic Model of the ACCRV. The contract included a functional checkout of the dynamic model, the results of which are included in this report (Section 11.3).

1.1 General

Current aircraft fire and rescue vehicles, including the P-19, have limited capability to operate over rough and low strength ground surfaces, especially soft, wet ground or marsh and snow, with no capability for overwater operation. In a wartime environment, fire fighting and rescue will be further restricted because of craters, debris or unexploded bombs.

Improved fire fighting and rescue vehicular mobility is needed to increase the probability of successfully rescuing crew and passengers. This requires a radical departure from current fire and rescue vehicle designs. The successful operation of ACV's over austere surfaces, including swamps and water, suggests this technology be used to develop an air cushion augmented fire/rescue vehicle, and this is the basis for the current effort. The air cushion crash rescue (ACCRV) vehicle is required to perform a complete rescue from downed aircraft, by traversing a wide variety of surfaces. It incorporates a triage compartment, a high boom for access and a slide. Fire fighting equipment similar to the P-19 is also carried on the vehicle, but it can function as a rescue vehicle as well as a fire truck.

In the concept study completed during the initial phase of the program, Bell considered many variations of subsystems and components. The ACCRV concept design employed major components of the most up-to-date crash rescue trucks. It was similar in aspect to the P-19 'Rapid Intervention Vehicle' design specifically for fire suppression but it was somewhat larger, especially longer, had a more powerful engine, and incorporated an air cushion system which could be immediately deployed to completely support the vehicle for off-runway or overwater operation, and a combined overwater/overland drive consisting of four wheels and a small track system to augment vehicle propulsion in snow and over water. Its predicted performance met or exceeded all aspects of the requirements.

The PD configuration retained (Figures 1-1, 1-2, and 1-3) most of the concept design features with some minor changes and improvements such as the track system. Figure 1-1 shows the ACCRV in the wheeled operating mode and Figure 1-2 shows the vehicle in the air cushion deployed mode. Figure 1-3 shows the inboard profile with major systems depicted. Major systems of the ACCRV have been detailed in more depth for the PD, and a

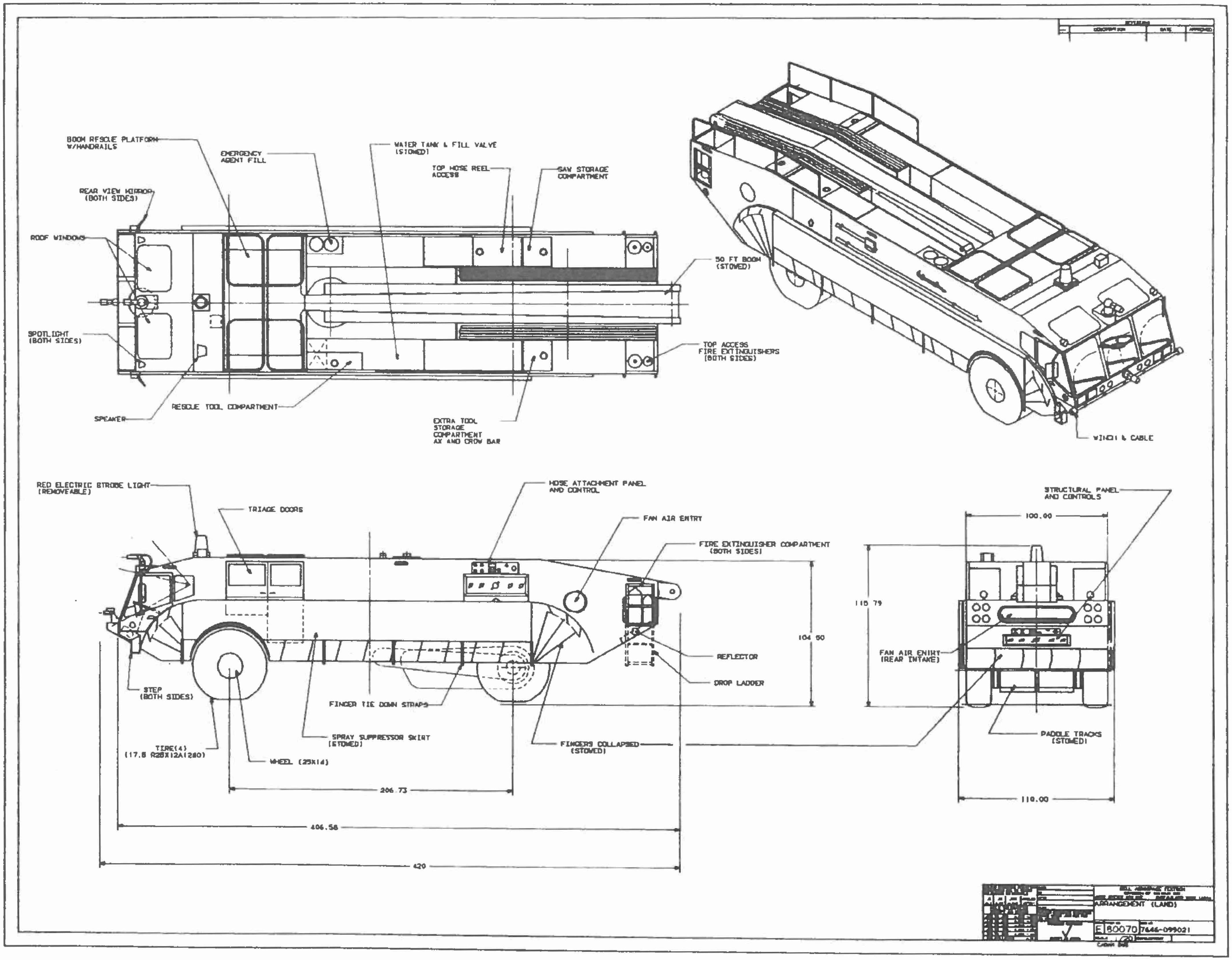

Figure 1-1. General Arrangement (Land)

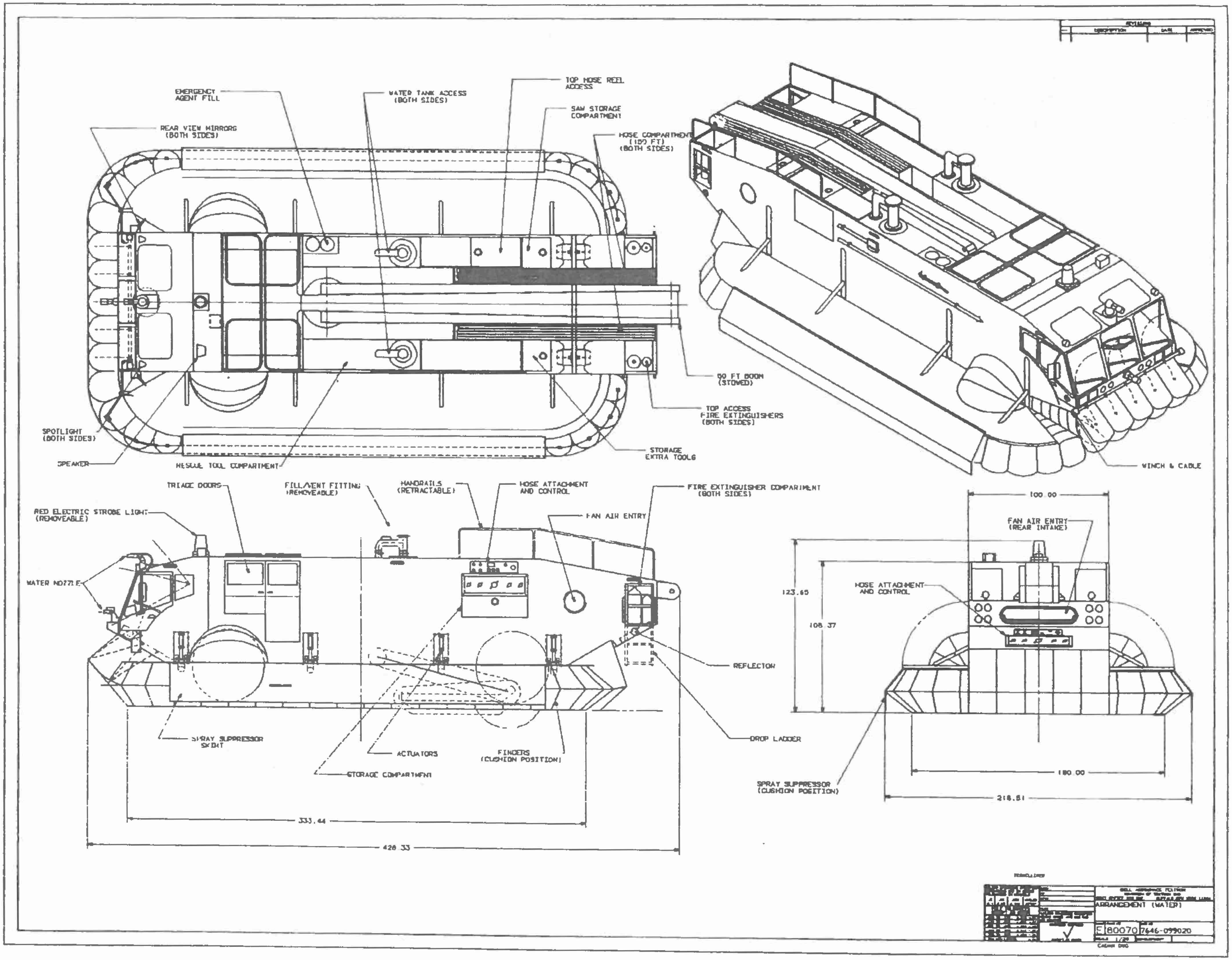

Figure 1-2. General Arrangement (Water)

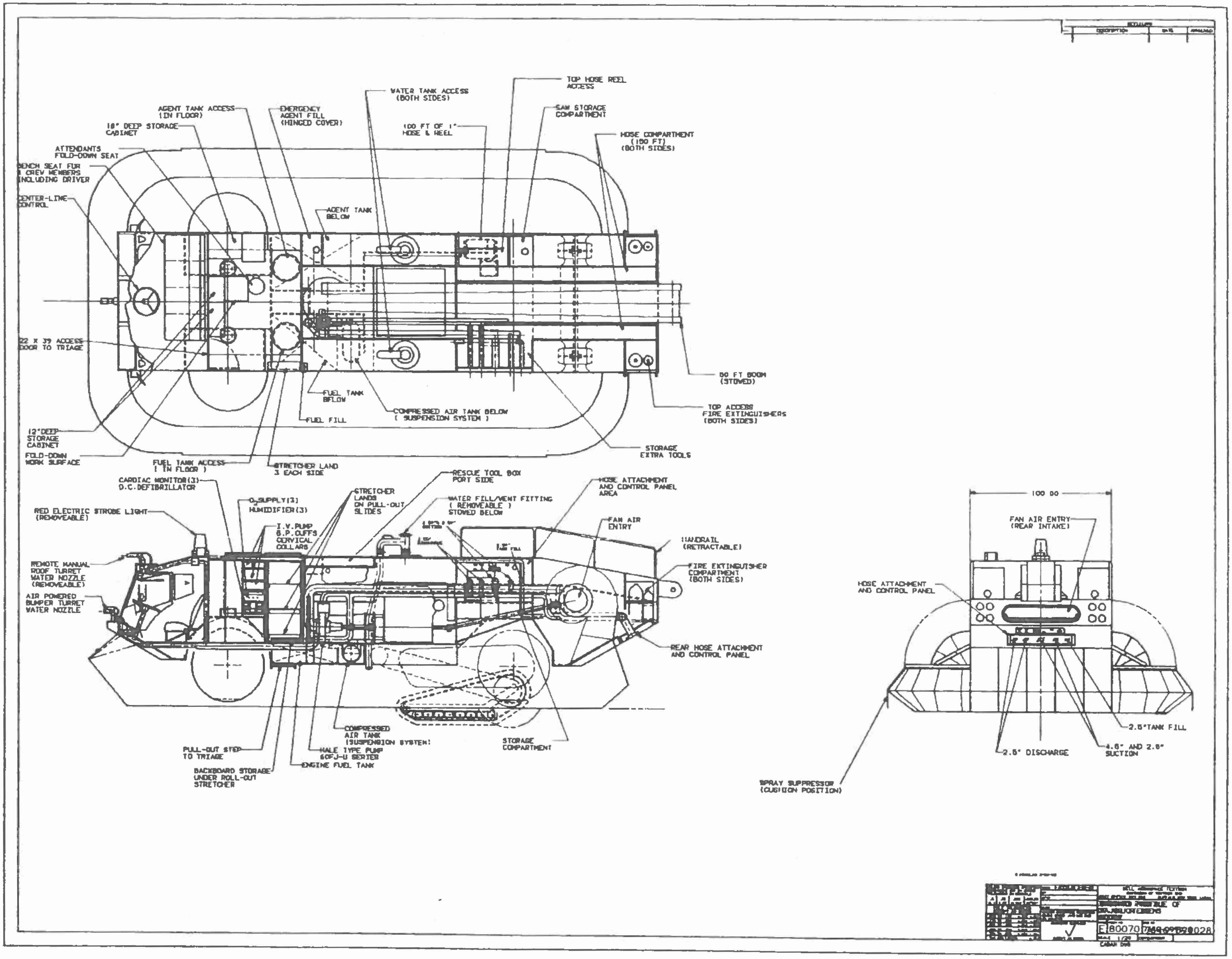

Figure 1-3. Inboard Profile

preliminary estimate of the vehicle's reliability and maintainability has been generated. A rough order of magnitude (ROM) estimate of production costs and schedules has also been prepared and is included in this report with recommendations for study which may reduce the production cost.

1.2 Configuration Constraints

The requirements to provide the performance of existing fire fighting vehicles including 65 mph roadway speed and 60% gradient capability besides other attributes, all suggest a conventional wheeled design for land mode. There is also a requirement for overwater operation with a water performance approaching 20 mph in a sea state of 1. Although the water performance requirement was subsequently reduced to less than 10 mph, the combined land/water performance is best achieved with a paddle track configuration (described in Section 5.3). This configuration is necessary for generation of needed drawbar pull over soft soils or snow while operating in the air cushion hybrid mode. The integration of the paddle track package within the vehicle envelope constraints is difficult, but this difficulty was eased somewhat by locating the package inboard of the rear wheels and powering the track from the rear wheel drive. Substantial reduction of tire load in the hybrid mode (using the air cushion) permits operation at much reduced tire footprint, hence providing increased traction and less tire sinkage. The large tires required for fully wheeled support in an off-road steep gradient situation are retained.

Vehicle gross weight is also a constraining factor as a result of the air transportability requirement. This requirement limits overall vehicle length, width and height, but it also forces a strong consideration of weight in the selection of components and even basic vehicle construction to meet the weight carrying capability of the transporting aircraft (the C-130). For example, to minimize weight, the selected ACCRV structure is fabricated from standard aluminum honeycomb sandwich panel with sufficient strength and stiffness to support structural loads. A second example is the use of fiber glass and carbon fiber in the construction of the boom. Commercial off-the-shelf booms for this application weigh considerably more (2500 lbs.) than the expected fiber glass unit (approximately 1000 lbs.).

The third major subsystem configuration driver is the provision of an optimum, combined, all-surface land-water-marsh-mud-snow propulsion method. Air propulsion has usually been chosen for ACV's because air propellers produce the same thrust over any surface. But in this case the air propeller is not attractive because it is not practical for the propeller disc to fit within the retracted head-on profile and provide adequate thrust with reasonable power limitation. In any case the wheels must be driven to achieve the required road performance. Thus a propulsion takeoff from the same drive is desirable and a method which provides satisfactory water propulsion is required. Water propellers are a pre-eminent candidate for water drive but must be retracted overland. This is feasible but a major difficulty arises in transition to land, especially low CBR (e.g., swamp ground): first the wheels must be well below the propeller disc so that they can take over propelling while the propeller is still submerged and clear of the bottom (similarly to amphibians such as the

Army's LARC-60); secondly, when cushionborne the propeller must be in the water below the cushion skirts, so that a considerable wheel extension both fore and aft must be provided or the transition from water to dry land must be accomplished hullborne; and finally the propeller is a hindrance over swampy ground, snow, etc.

These difficulties led to the rejection of the propeller in favor of a co-axial paddle track between the rear wheels, driven with the wheels at all times. The paddle track is used as a low speed water drive; it contributes significantly to propulsion and flotation over very soft ground, clay, marsh, mud and deep snow. The aft paddle track/tire combination is augmented by the front wheel drive in some terrain conditions. This is a combination which comes close to providing as consistent a drive over all surfaces as does the air propeller.

The three modes of vehicle operation are presented in Figure 1-4.

	WHEN USED	CONDITION
WHEELED	• HIGH SPEED ON ROADS • STEEP GRADES & SIDESLOPES • OFF THE ROAD FIRM SOIL GRAVEL SAND • PUMP AND DRIVE • FIREFIGHTING & RESCUE OPERATIONS	• LIFT SYSTEM STOWED • ALL WEIGHT SUPPORTED ON (4) WHEELS • 2 WHEEL/4 WHEEL DRIVE • FRONT WHEEL STEERING
CUSHIONBORNE	• OVER WATER • PUMP AND STATIONKEEP (FIREFIGHTING)	• LIFT SYSTEM DEPLOYED • 100% OF WT ON CUSHION • FRONT WHEELS RETRACTED • POWERED AND STEERED BY PADDLE TRACK
DISPLACEMENT	• OVER WATER WHEN BOOM OPERATION IS REQUIRED (RESCUE)	• CUSHION IS DEPLOYED BUT OFF • SIDE PANELS DEPLOYED • BOOM TRAVEL RESTRICTED TO +15°, -15°, UNLESS OPTIONAL STABILITY BAGS ARE INFLATED
HYBRID	• MARGINAL TERRAIN MARSH SNOW RICE PADDY BOMB CRATERS	• LIFT SYSTEM DEPLOYED • UP TO 30% WT ON REAR WHEELS/TRACKS REMAINDER ON CUSHION • FRONT WHEELS RETRACTED • PROPELLED BY PADDLE TRACKS • STEERED BY PADDLE TRACKS

Figure 1-4. Modes of Operation

2.0 VEHICLE CHARACTERISTICS

2.1 Vehicle Description

The ACCRV provides an improved fire fighting and rescue vehicle unlike any now in the military inventory. It incorporates the ability to conduct operations in adverse terrain and over water as well as in snow, swamps and, of course, in more conventional environments on or about airports. The integration of an air cushion system with a paddle track propulsor and a conventional four wheel drive system provides this versatility. The operational mode is selected by the vehicle operator as required.

The ACCRV also incorporates a deployable rescue boom and a triage bay with basic medical emergency equipment and supplies. This bay is designed to carry three stretcher cases and one attendant. A list of the emergency medical equipment available in the triage area is given in Section 9.2.2

In addition to serving as a fully equipped ambulance the ACCRV has all the firefighting capability of a P-19 fire truck. These features, together with its all-terrain capability, make the ACCRV the most advanced concept in rescue vehicle technology.

2.1.1 Instruments and Controls

Figure 2-1 is an overall view of the instruments and controls located in the cab. They may be functionally grouped as

a) Main and warning switches.
b) Running and driving instruments and controls.
c) Air cushion system controls and indicator.
d) Front axle control and indicator.
e) Paddle track control and indicator.
f) Firefighting instruments and controls.
g) Boom lock/unlock and indicator.
h) Aircraft loading switch.

These groups are discussed in more detail below.

a) Main and Warning Switches

The main switch panel, located in the center of the console, contains the engine starter and switches for parking lights, head lights, and interior lights, windshield wiper/washers, comfort controls, and windshield de-fogger/de-icers.

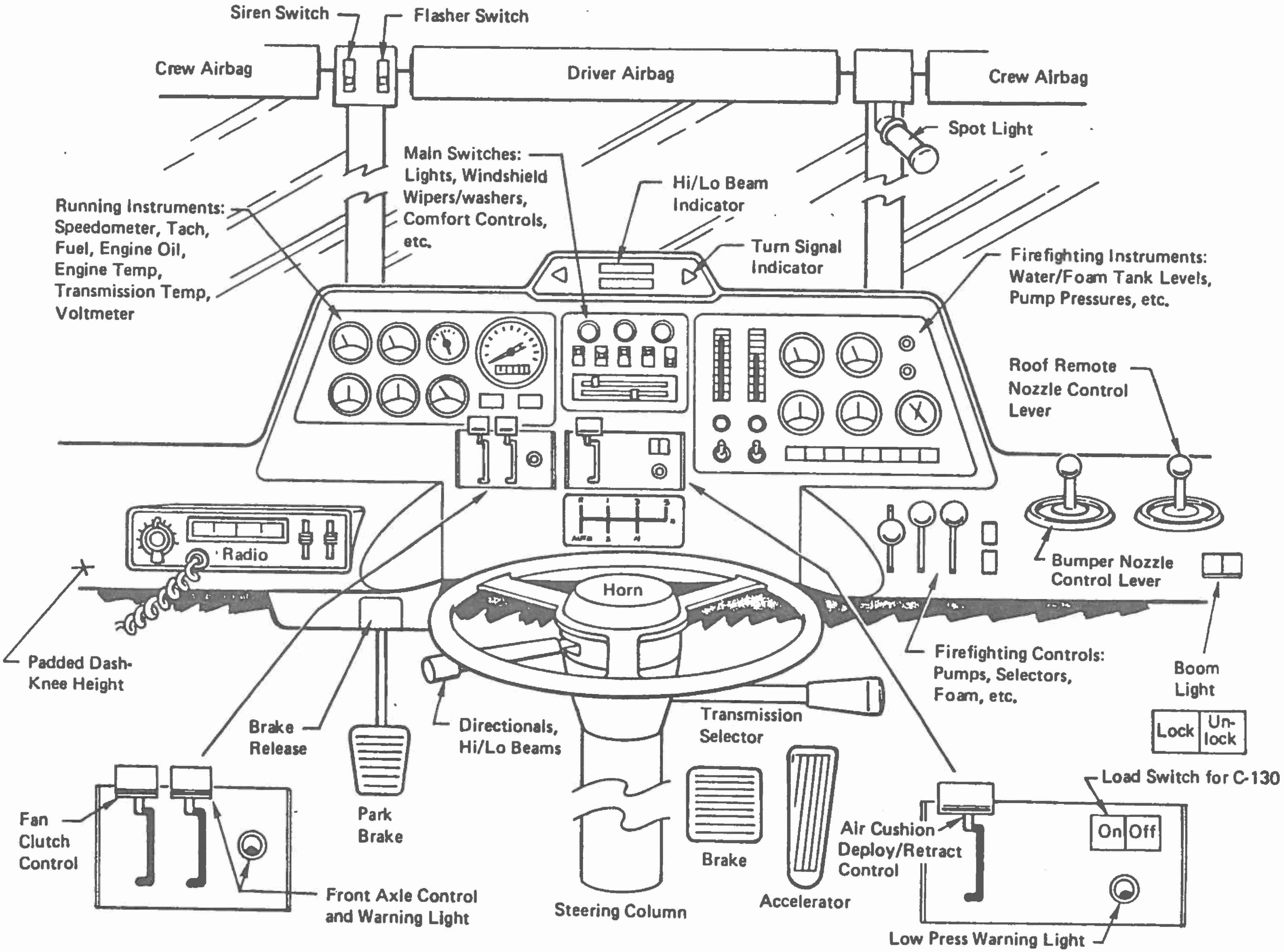

Figure 2-1. Operator's Instruments and Controls

The siren and flasher warning switches are within easy reach of the driver at the upper left hand corner of his windshield. The horn pad is in the center of the steering wheel.

b) Running and Driving Instruments and Controls

The running instrument panel is located to the left of the main switch panel. It comprises a speedometer, tachometer, fuel level indicator, engine oil pressure, engine and transmission temperature gages, and a voltmeter. The hi/lo beam indicator and turn signal indicators are positioned directly in front of the driver above the main switch panel.

Driving controls for the normal on-wheel mode are as for a typical truck. The accelerator and brake pedals are operated by the driver's right foot; the brake pedal being positioned between the steering wheel column and the accelerator pedal. The park brake and brake release are also in the normally accepted locations. The transmission selector and the directional - hi/lo beam lever are mounted on the steering column in the standard positions.

Transmission selection may be "automatic", reverse, or any one of the five forward gears. "Automatic" is used for most driving conditions. Low gear would be engaged for ascending steep grades or for the "drive and pump" mode. Fifth gear would be engaged for maximum speed over water with the paddle tracks deployed.

c) Air Cushion System Controls and Indicator

To deploy the air cushion, the driver must shift the transmission into neutral as the end of the runway approaches.

The air cushion deploy/retract control lever is located in the center of the console below the main switch panel. Movement of the lever then deploys the skirt. When it is fully deployed an amber light indicates to the driver that the fan clutch may now be engaged. The panel containing this lever is to the left of the air cushion control lever. Engagement of the fan clutch automatically disengages the power transmimssion clutch in the power divider, and sets the engine governer to 2300 rpm. Re-engagement of the power transmission clutch is achieved when the accelerator pedal is depressed after positioning the transmission selector.

d) Front Axle Control and Indicator

Raising and lowering the front axle is accomplished by moving the lever located to the immediate right of the fan clutch control. The front axle control lever can not be activated unless the air cushion control lever is in its "deploy" position. A red warning light next to the control lever indicates that the axle is in the raised position.

e) Firefighting Instruments and Controls

These instruments are contained in a panel on the right-hand side of the console. They indicate water tank level, foam tank level, pump pressure, air pressure, turret nozzle elevation/depression angle, sweep angle and oscillation rate. Low level warning lights are provided for the water and foam tanks.

The firefighting controls are situated below and to the right of the instruments. These include the pump clutch lever, nozzle selectors, water/foam selector, and dispersion selectors. Manual or automatic control of the roof nozzle may be chosen by a two-position switch, and if automatic control is selected the nozzle elevation/depression angle, the sweep angle, and the oscillation rate may be dialed in. If the manual mode is selected for the roof nozzle, then joystick control is achieved through the nozzle lever to the far right. The bumper nozzle control lever is to the immediate left of the roof nozzle control lever.

f) Boom Lock/Unlock and Indicator

The boom may be locked or unlocked from either the triage area or from the cab. The lock/unlock switch/indicator lights in the cab are located below and to the right of the roof nozzle joystick.

g) Aircraft Loading Switch

These on/off switch/indicator lights are on the center panel below the main switch group. Activation of the load switch causes the paddle track bogey cylinder to retract and to pivot the front of the paddle track bogey beam upward. This provides the additional clearance required for loading the vehicle on to a C-130 aircraft.

There are four additional control stations on the ACCRV. One in the triage bay, and a duplicate on the boom platform, control the boom motion and platform position. The platform mounted controls have authority over those in the triage bay. A hose attachment and control panel is located on the side of the vehicle above the left rear wheel. A second structural control panel which parallels all hose attachment and control functions is located at the rear of the vehicle. Details of these are given in Section 9.1.5.

2.2 Leading Particulars and Dimensions

The summary of leading particulars included in this section describe the physical and functional characteristics of the ACCRV shown in Figures 1-1, 1-2 and 1-3. These are the products of analyses and designs conducted during the Concept Definition and Preliminary Design phases of the ACCRV program.

2.2.1 General

Weight	Gross	30,877 lb.
	Empty	19,412 lb.
Load Capacity	Water	1,000 gal.
	Agent	150 gal.
	Fuel	75 gal. (diesel)
	Crew	4
	Passengers	4 (incl. 1 medical attendant, 3 patients on stretchers)
Dimensions	Wheeled	407L x 110W x 105H
	Hybrid	428L x 218W x 108H
	Reducible	407L x 110W x 105H

Wheelbase	202 in.
Approach/Departure Angle	30 degrees
Turning Diameter	100 ft. (wall to wall)
Air Transportability	C-130 (drive on, drive off)

2.2.2 Performance

Gross HP to Weight Ratio		49 (installed)
Land	(Wheeled)	65 mph max. 50 mph cruising
Water	(Cushionborne)	10 mph (SS-1) max.
Marginal Terrain	(Hybrid)	Terrain Dependent
Gradability	(Wheeled)	60% (Traction Limit)
"	(Hybrid)	5%
" (Pump & Drive)	(Wheeled)	40% @ 1 mph

2.2.3 Engine

Engine	DD8V92TA
Type	2 cycle, 8 cylinder diesel, turbo charged
Bore	4.84 inches
Stroke	5.0 inches
Displacement	736 cu. in.
Compression Ratio	17:1
Fuel	DF1, DF2, JP5 to JP8
Rated HP	736 (80 degree Day)
Control	Electronic with torque shaping/limiting option

2.2.4 Power Train

Transmission	Automatic Allison HT750 DR with TC 499 Torque Converter
Ratios	1st - 7.97:1 4th - 1.40:1 2nd - 3.19:1 5th - 1.00:1 3rd - 2.07:1 Rev - 4.47:1
Drop Box	1:1.08 ratio with drive to front and rear axle; integral bidirectional overrunning clutch.
Front Axle	Rockwell FDS 1600 single reduction hypoid gear with differential lock; 5.57:1 reduction, integral king pin and power assist arm.
Rear Axle	Eaton 16121 series single speed level gear with driver selected lockup differential, 3.55:1 reduction.
Transfer Case	Chain drive 1.57:1 reduction.

Power Divider	Multi disc oil cooled clutch with modulator to engage the main power transmission clutch.

2.2.5 Suspension

Suspension	Rigid Axle
Front	Coil springs/damper, cross axle.
Rear	Tube over-bar axle, coil springs-damper-adjustable load, extendable.
Tires (4)	Tubular radial 17.5 R25
Service Brakes	Internal shoe 17 x 5 in. hydraulic with power assist.
Frame	Integral aluminum honeycomb construction.

2.2.6 Lift System

Lift System	Single plenum, full depth finger configuration with retractable side panels.
Cushion Area	420 sq.ft.
Cushion Pressure	71.5 psf
Cushion Flow	980 cfs
Fan (2)	Dual double-entry centrifugal.
Fan Drive	Bevel gear splitter box with integral centrifugal clutch.

2.2.7 Flotation System

Flotation System	Optional 4 ft. dia. x 23 ft. long inflatable spray skirt.
Water, snow and soft surface propulsion	Dual paddle tracks directly coupled to the rear vehicle wheels - 23.5" sprocket dia. x 20 in. wide.

2.2.8 Fire Fighting System

Water Tank	1,000 gal. capacity integral, bladder lined.
Agent Tank	150 gal. capacity integral, bladder lined.
Water Pump Rating	Single Stage Hale 60FJ4-U3000 990 gpm at 225 psi at 3000 rpm
Discharge	500 gpm turret - manual 250 gpm bumper turret-automatic and manual. Hose reel, 95 gpm nozzle, 100 ft. hose.
Proportioning System	Around-the-pump type

Structural Connections	(1) 4-1/2 in. and (1) 2-1/2 in. sections. (2) 2-1/2 in. discharge (1) 2-1/2 in. tank fill (2) 2-1/2 in. emergency tank fill
Pump Drive	Direct flywheel PTO
Fire Extinguishers	(2) Size 2, per MIL-E-24091B (1) 17 lb. HALON 1211 2A.60 BC (1) 15 lb. HALON 1211 10 BC
Winterization	(1) Diesel fueled booster heater with distribution system.

2.2.9 Rescue

Boom/Platform	3 man capacity 42 ft. max. reach
Slide	Inflatable
Triage Area	3 injured personnel plus 1 attendant. Standard complement of medical equipment/supplies.
Auxiliary Equipment	Tool Kit FSN-4210-00-900-8557

2.3 Operational Scenarios

The scenario desacribed in this section has been selected to encompass all ACCRV operational modes. The series of events depicted represents a highly unlikely situation, but is chosen to demonstrate the actions required by the crew members under various conditions.

It is assumed that the crash site is a shallow lake a few miles off the end of the runway. A mud flat lies between the runway and the lake. The ACCRV is parked on a hard surface, with access to the runway by way of a paved road.

On hearing the alarm signal, the four crew members and one medical attendant proceed to the vehicle. The driver, the medical attendant, and one crew member enter through the left cab door, and take their places in the first two seats and in the triage area. Meanwhile the other two crew members take the two right seats, having entered through the right cab door. Access to the triage area is through the forward triage door on the left. A fold-down seat is provided for the attendant. All members buckle seat belts and the driver engages the engine start switch with the transmission selector in neutral. The engine will start automatically. The driver increases the engine speed to a little above idle by lightly depressing the accelerator pedal, checks the instruments, and moves the transmission selector to "automatic". Lights, windshield wipers, defogger, cab heater or air conditioner, are turned on as required. The parking brake is released and the vehicle is driven first to, then down the runway at the fastest safe speed. Driving in this mode is exactly the same as driving a truck with automatic transmission.

The driver will shift the transmission into neutral, as the end of the runway approaches. Air cushion deployment is activated by a lever located in the center of the driver's control panel. The following actions are automatically sequenced when the lever is operated. First, the side panels are rotated by 4 hydraulic actuators on each side of the craft. Then electric motor driven winches at the front, back and on each side of the vehicle slide the finger-restraining cables to release the fingers from their stowed positions. When the cushion deployment procedure has been completed an amber light indicates that the driver may now engage the fans. This is achieved by moving a lever on a second panel (see Figure 2-1) that hydraulically activates the fan clutch. This action also causes the power transmission clutch in the power divider to be disengaged, and to automatically set the engine governed speed to 2300 rpm. The driver selects a gear, re-engages the main power transmission clutch by depressing the accelerator pedal and proceeds. If the selector is in "automatic", the transmission will sequentially progress through the gears as required. Paddle track deployment is achieved by activation of a separate air cushion deployment lever. This lever starts the sequence that first hydraulically retracts the bogey cylinder, then charges the deployment actuator with air. The paddle track may be deployed with the vehicle stationary or moving in first gear.

On reaching the lake, the driver has the option of retracting the front axle by moving a lever on the control panel. This directs hydraulic fluid to the retraction mechanism. A red warning light is displayed when the axle is in the retracted position.

The vehicle proceeds across the lake with differential track braking being used for steering. This mode of steering is automatically engaged when the paddle track is deployed. The driver simply steers as he would on land, but steering wheel rotation is now used to brake the tracks differentially.

On reaching the crash site, and seeing that the aircraft is on fire, the crew member to the right of the driver engages the water pump clutch. He assesses the fire hazard and selects which nozzle or nozzles should be employed. He also decides on joystick or automatic control if the turret nozzle is selected, and also on the discharge pattern and oscilation rate.

The driver, realizing that the rescue boom must be deployed to reach the crash victims, disengages the fan clutch, thereby putting the craft in the floating mode and unlocks the boom. The crew member to the driver's left enters the triage area through the access door to his left rear, from where he can operate the boom controls. As the driver turns the craft so that its bow points to within +/- 20 degrees of the desired boom direction, the crew member in the triage area climbs onto the boom platform through a trap door and using the rail-mounted controls extends the boom to reach the crash victims. They are transferred to the triage bay where the medical attendant supplies first aid as necessary. The boom is stowed by operation of the triage area control panel, and the fire-fighting nozzles are deactivated.

The driver engages the fan clutch to bring the craft back on-cushion, and with the transmission in fifth gear heads back across the lake. On reaching the end of the runway the driver must make the decision whether to convert to the basic wheeled mode, or to remain in the hybrid mode. In either case the front axle will be lowered, if retracted, and the paddle tracks will be stowed. From the point of view of finger wear it is preferable to convert to the basic wheeled mode (air cushion stowed); in a medical emergency the driver would not jeopardize the patient's life by slowing the vehicle to stow the lift system.

2.4 Mass Properties Analysis

2.4.1 Introduction

To meet the ACCRV operational land and water performance requirements, vehicle weight, c.g. location, and moments have been carefully controlled. This has been factored into all subsystem selection and location trade-offs, along with the placement of variable loads (passengers, fuel, water, and aqueous foam).

2.4.2 Mass Properties Analysis

A comprehensive mass properties analysis of the ACCRV preliminary design was conducted for various operating conditions between empty and gross weight. Weights, center-of-gravity location and vehicle moments of inertia were estimated using drawing analyses and information residence in a Bell data base acquired on previous air cushion vehicle hardware and vehicle study programs.

The current empty weight of the ACCRV is 19,412 lbs. Addition of 4 crewmembers (680 lbs.), 4 passengers (680 lbs.), 100% fuel load (585 lbs.), water (8330 lbs.) and aqueous foam (1250 lbs.) to the empty vehicle weight results in a loaded weight of 30,877 pounds. Note there is a third condition, which is the flight condition. This weight (21,867 lbs.) does not include the passengers (680 lbs.) or the water, because it is anticipated that passengers and water would not be transported by the C-130, at least not in this vehicle, so this weight should not be included in the weight statement. Complete mass properties estimates for the empty, fully loaded, and flight condition ACCRV are summarized in Figure 2.4-1. Based on previous experience on similar programs at Bell, a weight control margin of 3% of the ACCRV empty weight is included in the weight statements. This margin compensates for weight uncertainties inherent in a preliminary design phase.

Eighteen operating weight conditions were examined with various expenditures of on-board disposable loads such as fuel, water, aqueous foam and varying the number of passengers. Figure 2.4-2 lists the cases analyzed and shows the summarized results. These data were used to develop an operating longitudinal c.g. envelope of possible vehicle configurations. Varying disposable loads causes a maximum dispersion of the veritcal center-of-gravity (c.g.) position of 9.5 inches. Lateral c.g. location variance is small, the maximum difference being 1.9 inch. The maximum variation in the longitudinal position is 6.4 inches. Weight estimates for the fully loaded condition are based on layout analysis (17.0% of weight), procurement sources (19.9%), customer data and equipment lists (35.9%), empirical analysis (4.8%), performance analysis requirements (1.7%) and statistical methods (20.7%).

ACCRV WEIGHT, CENTER OF GRAVITY LOCATION AND MOMENTS OF INERTIA

WBS	DESCRIPTION	WT(LB)	X(IN)	Y(IN)	Z(IN)	WT*X	WT*Y	WT*Z	WT*X^2	WT*Y^2	WT*Z^2	ISELFxx	ISELFyy	ISELFzz	LX	LY	LZ
1.01.01	HULL, STRUCTURAL FRAME	2112.0	226.0	0.0	40.0	4.773E+05	0.000E+00	8.448E+04	1.079E+08	0.000E+00	3.379E+06	2.804E+06	1.484E+07	1.556E+07	280.0	100.0	77.0
1.01.02	CAB AND EQUIPMENT COMPARTMENTS	1082.0	40.0	0.0	30.0	4.328E+04	0.000E+00	3.246E+04	1.731E+06	0.000E+00	9.738E+05	1.343E+06	7.146E+05	1.174E+06	55.0	100.0	70.0
1.01.03	PLATFORM AND PLATFORM STRUCTURE	129.0	110.0	0.0	75.0	1.419E+04	0.000E+00	9.675E+03	1.561E+06	0.000E+00	7.256E+05	8.725E+04	3.634E+04	1.232E+05	58.0	90.0	4.0
1.01.04	CREW AND PASSENGER ACCOMODATIONS	232.0	50.0	0.0	40.0	1.160E+04	0.000E+00	9.280E+03	5.800E+05	0.000E+00	3.712E+05	6.187E+04	1.005E+05	1.005E+05	60.0	40.0	40.0
1.01.05	APPENDAGES	113.0	174.0	0.0	40.0	1.966E+04	0.000E+00	4.520E+03	3.421E+06	0.000E+00	1.808E+05	7.533E+04	6.516E+05	6.968E+05	260.0	80.0	40.0
1.01.06	FUEL TANK BLADDER	23.0	149.0	-28.0	5.0	3.427E+03	-6.440E+02	1.150E+02	5.106E+05	1.803E+04	5.750E+02	3.534E+03	6.356E+03	8.357E+03	54.0	38.0	20.0
1.01.07	INTEGRATION AND ASSEMBLY	258.0	174.0	0.0	40.0	4.489E+04	0.000E+00	1.032E+04	7.811E+06	0.000E+00	4.128E+05	1.570E+05	1.473E+06	1.591E+06	260.0	80.0	30.0
1.01.00	HULL AND FRAME SUBTOTAL	WT(LB) 3949.0	XCG(IN) 155.6	YCG(IN) -0.2	ZCG(IN) 38.2	WT*X 6.144E+05	WT*Y -6.440E+02	WT*Z 1.509E+05	WT*X^2 1.235E+08	WT*Y^2 1.803E+04	WT*Z^2 6.044E+06	ISELFxx 4.532E+06	ISELFyy 1.782E+07	ISELFzz 1.925E+07	LX	LY	LZ
1.02.01	SPRING SYSTEM	412.0	178.0	0.0	10.0	7.334E+04	0.000E+00	4.120E+03	1.305E+07	0.000E+00	4.120E+04	1.991E+05	1.350E+06	1.487E+06	196.0	70.0	30.0
1.02.02	FRONT AXLE (INCL. DIFFERENTIAL, STEERING, BRAKE DRUMS)	1133.0	80.0	0.0	0.0	9.064E+04	0.000E+00	0.000E+00	7.251E+06	0.000E+00	0.000E+00	5.004E+05	7.553E+04	5.004E+05	20.0	70.0	20.0
1.02.03	REAR AXLE (INCL. DIFFERENTIAL, BRAKES, DRUMS, YOKES)	798.0	276.0	0.0	-20.0	2.202E+05	0.000E+00	-1.596E+04	6.079E+07	0.000E+00	3.192E+05	3.525E+05	5.320E+04	3.525E+05	20.0	70.0	20.0
1.02.04	WHEELS (4)	1170.0	178.0	0.0	-10.0	2.083E+05	0.000E+00	-1.170E+04	3.707E+07	0.000E+00	1.170E+05	5.387E+05	3.806E+06	4.223E+06	196.0	70.0	25.0
1.02.05	TIRES (4)	1339.0	178.0	0.0	-10.0	2.383E+05	0.000E+00	-1.339E+04	4.242E+07	0.000E+00	1.339E+05	7.727E+05	4.513E+06	4.833E+06	196.0	70.0	45.0
1.02.06	WEIGHT DISTRIBUTION SYSTEM (STRUTS)	232.0	258.0	0.0	20.0	5.986E+04	0.000E+00	4.640E+03	1.544E+07	0.000E+00	9.280E+04	1.184E+05	2.803E+04	9.908E+04	15.0	70.0	35.0
1.02.07	CONTROLS	36.0	20.0	0.0	40.0	7.200E+02	0.000E+00	1.440E+03	1.440E+04	0.000E+00	5.760E+04	1.275E+03	3.750E+02	1.500E+03	10.0	20.0	5.0
1.02.08	INTEGRATION AND ASSEMBLY	15.0	178.0	0.0	30.0	2.670E+03	0.000E+00	4.500E+02	4.753E+05	0.000E+00	1.350E+04	6.156E+03	4.805E+04	5.415E+04	196.0	70.0	5.0
1.02.00	SUSPENSION SUBTOTAL	WT(LB) 5135.0	XCG(IN) 174.1	YCG(IN) 0.0	ZCG(IN) -5.9	WT*X 8.941E+05	WT*Y 0.000E+00	WT*Z -3.040E+04	WT*X^2 1.765E+08	WT*Y^2 0.000E+00	WT*Z^2 7.752E+05	ISELFxx 2.489E+06	ISELFyy 9.874E+06	ISELFzz 1.155E+07	LX	LY	LZ

Figure 2.4-1. ACCRV Mass Properties Analysis

1.03.01	ENGINE	2318.0	214.0	0.0	35.0	4.961E+05	0.000E+00	8.113E+04	1.062E+08	0.000E+00	2.840E+06	3.574E+05	4.105E+05	2.946E+05	30.0	25.0	35.0
1.03.02	INDUCTION/EXHAUST	129.0	214.0	0.0	35.0	2.761E+04	0.000E+00	4.515E+03	5.908E+06	0.000E+00	1.580E+05	5.375E+03	1.075E+04	1.398E+04	30.0	20.0	10.0
1.03.03	COOLING/RADIATOR	219.0	244.0	0.0	45.0	5.344E+04	0.000E+00	9.855E+03	1.304E+07	0.000E+00	4.435E+05	5.439E+04	1.250E+04	4.221E+04	3.0	48.0	26.0
1.03.04	ENGINE CONTROLS	26.0	214.0	0.0	35.0	5.564E+03	0.000E+00	9.100E+02	1.191E+06	0.000E+00	3.185E+04	1.083E+03	1.083E+03	1.733E+03	20.0	20.0	10.0
1.03.05	POWER TAKE-OFFS (INCL. 1.03.01)																
1.03.06	ENGINE ELECTRICAL (INCL. 1.03.01)																
1.03.07	INTEGRATION AND ASSEMBLY	26.0	278.0	0.0	0.0	7.228E+03	0.000E+00	0.000E+00	2.009E+06	0.000E+00	0.000E+00	9.208E+02	9.208E+02	1.733E+03	20.0	20.0	5.0
1.03.00	PROPULSION	WT(LB)	XCG(IN)	YCG(IN)	ZCG(IN)	WT*X	WT*Y	WT*Z	WT*X^2	WT*Y^2	WT*Z^2	ISELFxx	ISELFyy	ISELFzz	LX	LY	LZ
	SUBTOTAL	2718.0	217.0	0.0	35.5	5.899E+05	0.000E+00	9.641E+04	1.283E+08	0.000E+00	3.473E+06	4.191E+05	4.357E+05	3.542E+05			
1.04.01	TRANSMISSION, WET	1082.0	164.0	0.0	26.0	1.774E+05	0.000E+00	2.813E+04	2.910E+07	0.000E+00	7.314E+05	6.528E+04	1.735E+05	1.803E+05	40.0	20.0	18.0
1.04.02	TRANSFER CASE (DROP BOX)	103.0	140.0	0.0	16.0	1.442E+04	0.000E+00	1.648E+03	2.019E+06	0.000E+00	2.637E+04	5.493E+03	5.253E+03	8.583E+02	6.0	8.0	24.0
1.04.03	POWER DIVIDER	480.0	190.0	0.0	27.4	9.120E+04	0.000E+00	1.315E+04	1.733E+07	0.000E+00	3.604E+05	2.592E+04	1.492E+04	1.492E+04	7.0	18.0	18.0
1.04.04	SHAFTS AND COUPLINGS	170.0	178.0	0.0	8.0	3.026E+04	0.000E+00	1.360E+03	5.386E+06	0.000E+00	1.088E+04	4.817E+02	2.044E+05	2.041E+05	120.0	3.0	5.0
1.04.05	DISK BRAKES AND CONTROLS (INCL.IN 102.02; 102.03)																
1.04.06	STEERING CONTROLS	160.0	60.0	0.0	10.0	9.600E+03	0.000E+00	1.600E+03	5.760E+05	0.000E+00	1.600E+04	2.267E+04	3.333E+04	1.333E+04	30.0	10.0	40.0
1.04.07	THROTTLE/REVERSE/FUEL CONTROLS	26.0	178.0	0.0	0.0	4.628E+03	0.000E+00	0.000E+00	8.238E+05	0.000E+00	0.000E+00	4.333E+02	1.083E+03	1.083E+03	20.0	10.0	10.0
1.04.08	CLUTCHES/COUPLINGS	185.0	178.0	0.0	28.0	3.293E+04	0.000E+00	5.180E+03	5.862E+06	0.000E+00	1.450E+05	1.233E+04	7.708E+03	7.708E+03	10.0	20.0	20.0
1.04.09	REAR AXLE DRIVE CHAIN & BOX	252.0	267.0	0.0	-8.0	6.728E+04	0.000E+00	-2.016E+03	1.796E+07	0.000E+00	1.613E+04	9.710E+04	7.400E+04	1.281E+05	50.0	60.0	32.0
1.04.10	PADDLETRACKS	724.0	231.0	0.0	-22.0	1.672E+05	0.000E+00	-1.593E+04	3.863E+07	0.000E+00	3.504E+05	2.597E+05	3.137E+05	3.803E+05	60.0	52.0	40.0
1.04.11	INTEGRATION AND ASSEMBLY	26.0	178.0	0.0	30.0	4.628E+03	0.000E+00	7.800E+02	8.238E+05	0.000E+00	2.340E+04	5.633E+03	2.188E+04	2.708E+04	100.0	50.0	10.0
1.04.00	AUTOMOTIVE/MARINE DRIVE TRAIN	WT(LB)	XCG(IN)	YCG(IN)	ZCG(IN)	WT*X	WT*Y	WT*Z	WT*X^2	WT*Y^2	WT*Z^2	ISELFxx	ISELFyy	ISELFzz	LX	LY	LZ
	SUBTOTAL	3208.0	186.9	0.0	10.6	5.996E+05	0.000E+00	3.391E+04	1.185E+08	0.000E+00	1.680E+06	4.950E+05	8.498E+05	9.579E+05			
1.05.01	FOLD-DOWN PANELS AND HARDWARE	525.0	174.0	0.0	1.0	9.135E+04	0.000E+00	5.250E+02	1.589E+07	0.000E+00	5.250E+02	1.418E+06	3.955E+04	1.457E+06	30.0	180.0	2.0
1.05.02	FINGERS AND ATTACHMENTS	536.0	186.0	0.0	-10.0	9.970E+04	0.000E+00	-5.360E+03	1.854E+07	0.000E+00	5.360E+04	1.750E+06	5.064E+06	6.711E+06	335.0	195.0	34.0
1.05.03	RETRACTION SYSTEM	155.0	182.0	0.0	10.0	2.821E+04	0.000E+00	1.550E+03	5.134E+06	0.000E+00	1.550E+04	1.596E+05	8.765E+05	1.029E+06	260.0	110.0	16.0
1.05.00	SKIRT SYSTEM	WT(LB)	XCG(IN)	YCG(IN)	ZCG(IN)	WT*X	WT*Y	WT*Z	WT*X^2	WT*Y^2	WT*Z^2	ISELFxx	ISELFyy	ISELFzz	LX	LY	LZ
	SUBTOTAL	1216.0	180.3	0.0	-2.7	2.193E+05	0.000E+00	-3.265E+03	3.957E+07	0.000E+00	6.963E+04	3.327E+06	5.980E+06	9.198E+06			

Figure 2.4-1. ACCRV Mass Properties Analysis (Cont)

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1.06.01  FAN ASSEMBLIES (2)                      335.0   330.0     0.0    36.0   1.106E+05  0.000E+00  1.206E+04  3.648E+07  0.000E+00  4.342E+05  2.268E+05  1.703E+05  2.575E+05   60.0   75.0   50.0

1.06.02  DRIVE SHAFTS/COUPLINGS                  129.0   278.0     0.0    30.0   3.586E+04  0.000E+00  3.870E+03  9.970E+06  0.000E+00  1.161E+05  1.247E+03  5.375E+04  5.285E+04   70.0    4.0   10.0

1.06.03  SHAFT AND GEARBOX                       187.0   326.0     0.0    35.0   6.096E+04  0.000E+00  6.545E+03  1.987E+07  0.000E+00  2.291E+05  8.477E+03  5.750E+03  9.740E+03   15.0   20.0   12.0

1.06.04  FAN CONTROLS                             20.0   330.0     0.0    36.0   6.600E+03  0.000E+00  7.200E+02  2.178E+06  0.000E+00  2.592E+04  3.333E+02  8.333E+02  8.333E+02   20.0   10.0   10.0

1.06.05  INTEGRATION AND ASSEMBLY                 20.0   330.0     0.0    36.0   6.600E+03  0.000E+00  7.200E+02  2.178E+06  0.000E+00  2.592E+04  3.333E+02  6.167E+03  6.167E+03   60.0   10.0   10.0
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1.06.00  LIFT SYSTEM                            WT(LB) XCG(IN) YCG(IN) ZCG(IN)     WT*X       WT*Y       WT*Z     WT*X^2     WT*Y^2     WT*Z^2    ISELFxx    ISELFyy    ISELFzz       LX     LY     LZ
         SUBTOTAL                                691.0   319.2     0.0    34.6   2.206E+05  0.000E+00  2.392E+04  7.068E+07  0.000E+00  8.312E+05  2.372E+05  2.368E+05  3.271E+05
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1.07.01  VEHICLE ELECTRICAL SYSTEM               438.0   210.0     0.0    35.0   9.198E+04  0.000E+00  1.533E+04  1.932E+07  0.000E+00  5.366E+05  6.570E+04  6.570E+04  6.570E+04   30.0   30.0   30.0

1.07.02  VEHICLE HYDRAULIC SYSTEM                 82.0   178.0     0.0    10.0   1.460E+04  0.000E+00  8.200E+02  2.598E+06  0.000E+00  8.200E+03  5.467E+03  5.467E+03  5.467E+03   20.0   20.0   20.0

1.07.03  BOOM SYSTEM                             995.0   230.0     0.0    62.0   2.289E+05  0.000E+00  6.169E+04  5.264E+07  0.000E+00  3.825E+06  7.695E+04  5.194E+06  5.247E+06  250.0   28.0   12.0

1.07.04  BILGE SYSTEM                             31.0   178.0     0.0    10.0   5.518E+03  0.000E+00  3.100E+02  9.822E+05  0.000E+00  3.100E+03  5.167E+02  5.167E+02  5.167E+02   10.0   10.0   10.0

1.07.05  ENVIRONMENTAL CONTROL (A/C, HEAT)       206.0    65.0     0.0    40.0   1.339E+04  0.000E+00  8.240E+03  8.704E+05  0.000E+00  3.296E+05  3.090E+04  3.090E+04  3.090E+04   30.0   30.0   30.0

1.07.06  AUXILIARY EQUIPMENT (HOSES, REELS)      361.0   276.0     0.0    60.0   9.964E+04  0.000E+00  2.166E+04  2.750E+07  0.000E+00  1.300E+06  2.407E+05  1.564E+05  3.008E+05   60.0   80.0   40.0

1.07.07  FUEL SYSTEM                              67.0   130.0   -30.0    10.0   8.710E+03 -2.010E+03  6.700E+02  1.132E+06  6.030E+04  6.700E+03  1.117E+03  2.792E+03  2.792E+03   20.0   10.0   10.0

1.07.08  COMPRESSED AIR SYSTEM                    93.0   178.0     0.0    20.0   1.655E+04  0.000E+00  1.860E+03  2.947E+06  0.000E+00  3.720E+04  6.200E+03  6.200E+03  6.200E+03   20.0   20.0   20.0

1.07.09  PUMPING SYSTEMS                         196.0   190.0     0.0    35.0   3.724E+04  0.000E+00  6.860E+03  7.076E+06  0.000E+00  2.401E+05  1.307E+04  1.307E+04  1.307E+04   20.0   20.0   20.0

1.07.10  INTEGRATION AND ASSEMBLY                 26.0   178.0     0.0    40.0   4.628E+03  0.000E+00  1.040E+03  8.238E+05  0.000E+00  4.160E+04  5.471E+03  5.471E+03  1.083E+04   50.0   50.0    5.0
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1.07.00  AUXILIARY SYSTEMS                      WT(LB) XCG(IN) YCG(IN) ZCG(IN)     WT*X       WT*Y       WT*Z     WT*X^2     WT*Y^2     WT*Z^2    ISELFxx    ISELFyy    ISELFzz       LX     LY     LZ
         SUBTOTAL                               2495.0   208.9    -0.8    47.5   5.211E+05 -2.010E+03  1.185E+05  1.159E+08  6.030E+04  6.327E+06  4.461E+05  5.481E+06  5.684E+06
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         EMPTY CONDITION                        WT(LB) XCG(IN) YCG(IN) ZCG(IN)     WT*X       WT*Y       WT*Z     WT*X^2     WT*Y^2     WT*Z^2    ISELFxx    ISELFyy    ISELFzz
         TOTAL                                 19412.0   188.5    -0.1    20.1   3.659E+06 -2.654E+03  3.899E+05  7.730E+08  7.833E+04  1.920E+07  1.195E+07  4.068E+07  4.732E+07


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Figure 2.4-1. ACCRV Mass Properties Analysis (Cont)

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1.08.01  FUEL (75 GAL.)           525.0   142.0   -28.0     4.0  7.455E+04 -1.470E+04  2.100E+03  1.059E+07  4.116E+05  8.400E+03  6.755E+04  1.320E+05  1.908E+05   54.0   38.0   10.0

1.08.02  WATER (1000 GAL.)       8330.0   188.0     0.0    55.0  1.566E+06  0.000E+00  4.582E+05  2.944E+08  0.000E+00  2.520E+07  8.653E+06  9.763E+06  1.391E+07  104.0   96.0   57.0

1.08.03  AGENT (150 GAL.)        1250.0   188.0    28.0    10.0  2.350E+05  3.500E+04  1.250E+04  4.418E+07  9.800E+05  1.250E+05  1.771E+05  4.017E+05  5.254E+05   60.0   38.0   16.0

1.08.04  CREW (4)                 680.0    50.0     0.0    60.0  3.400E+04  0.000E+00  4.080E+04  1.700E+06  0.000E+00  2.448E+06  5.553E+05  3.683E+05  3.683E+05   40.0   70.0   70.0

1.08.05  PASSENGERS (4)           680.0   100.0     0.0    60.0  6.800E+04  0.000E+00  4.080E+04  6.800E+06  0.000E+00  2.448E+06  5.553E+05  3.683E+05  3.683E+05   40.0   70.0   70.0
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1.08.00  LOAD                    WT(LB)  XCG(IN) YCG(IN) ZCG(IN)    WT*X       WT*Y       WT*Z      WT*X^2     WT*Y^2     WT*Z^2    ISELFxx    ISELFyy    ISELFzz     60.0    4.0   12.0
         SUBTOTAL               11465.0   172.5     1.8    48.4  1.978E+06  2.030E+04  5.544E+05  3.577E+08  1.392E+06  3.023E+07  1.001E+07  1.103E+07  1.536E+07
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         LOADED CONDITION        WT(LB)  XCG(IN) YCG(IN) ZCG(IN)    WT*X       WT*Y       WT*Z      WT*X^2     WT*Y^2     WT*Z^2    ISELFxx    ISELFyy    ISELFzz
         TOTAL                  30877.0   182.5     0.6    30.6  5.636E+06  1.765E+04  9.442E+05  1.131E+09  1.470E+06  4.943E+07  2.195E+07  5.172E+07  6.268E+07


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                                          ACCRV MASS PROPERTIES ANALYSIS SUMMARY


                                                   C.G. LOCATION                      MOMENTS OF INERTIA (ABOUT C.G. AXIS)


             EMPTY CONDITION:

                        WEIGHT =  19412.0 LB.       XCG =    188.5 IN.                   Ixx =    2.339E+07 LB-IN^2
                                                    YCG =     -0.1 IN.                   Iyy =    1.354E+08 LB-IN^2
                                                    ZCG =     20.1 IN.                   Izz =    1.307E+08 LB-IN^2


             LOADED CONDITION:

                        WEIGHT =  30877.0 LB.       XCG =    182.5 IN.                   Ixx =    4.397E+07 LB-IN^2
                                                    YCG =      0.6 IN.                   Iyy =    1.740E+08 LB-IN^2
                                                    ZCG =     30.6 IN.                   Izz =    1.659E+08 LB-IN^2


             FLIGHT CONDITION:

                        WEIGHT =  21867.0 LB.       XCG =    183.0 IN.                   Ixx =    2.692E+07 LB-IN^2
                                                    YCG =      0.8 IN.                   Iyy =    1.511E+08 LB-IN^2
                                                    ZCG =     20.4 IN.                   Izz =    1.467E+08 LB-IN^2

         NOTE:  THE ORIGIN OF THE COORDINATE SYSTEM IS LOCATED AT
                THE VEHICLE FRONT CENTER, IN PLANE WITH THE LOWEST
                HORIZONTAL SURFACE.
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Figure 2.4-1. ACCRV Mass Properties Analysis (Concluded)

CONDITION #	# PASSENGERS	# CREW	% FUEL	% WATER	% FOAM	GROSS VEHICLE WEIGHT LB	CENTER OF GRAVITY (IN.)			MOMENTS OF INERTIA LB-IN^2		
							X	Y	Z	Ixx	Iyy	Izz
1	0	4	100	100	100	30197.0	184.4	0.6	29.9	4.281E+07	1.683E+08	1.608E+08
2	0	4	100	50	100	26032.0	183.8	0.7	25.9	3.544E+07	1.603E+08	1.537E+08
3	0	4	25	0	0	20223.0	183.5	-0.3	21.3	2.515E+07	1.497E+08	1.441E+08
4	0	4	25	25	25	22617.0	184.0	0.1	24.3	2.981E+07	1.545E+08	1.480E+08
5	0	4	25	50	50	25013.0	184.4	0.4	26.6	3.415E+07	1.589E+08	1.518E+08
6	2	4	50	50	50	25484.0	183.0	0.3	27.0	3.499E+07	1.622E+08	1.546E+08
7	2	4	25	0	0	20563.0	182.1	-0.3	22.0	2.593E+07	1.527E+08	1.466E+08
8	2	4	25	25	25	22617.0	182.8	0.1	24.8	3.052E+07	1.574E+08	1.505E+08
9	2	4	100	100	100	30537.0	183.5	0.6	30.3	4.339E+07	1.712E+08	1.633E+08
10	4	4	100	100	100	30877.0	182.5	0.5	30.6	4.397E+07	1.740E+08	1.659E+08
11	4	4	100	0	100	22547.0	180.5	0.8	21.6	2.851E+07	1.571E+08	1.516E+08
12	4	4	100	50	100	26712.0	181.7	0.7	26.8	3.677E+07	1.661E+08	1.588E+08
13	4	4	0	100	100	30352.0	183.2	1.1	31.0	4.309E+07	1.726E+08	1.644E+08
14	4	4	50	100	100	30614.0	182.9	0.8	30.8	4.353E+07	1.733E+08	1.651E+08
15	4	4	100	0	0	21297.0	180.1	-0.8	22.2	2.717E+07	1.564E+08	1.500E+08
16	0	2	25	0	0	19883.0	185.8	-0.3	20.7	2.436E+07	1.428E+08	1.377E+08
17	0	2	25	50	50	24673.0	186.2	0.5	26.2	3.349E+07	1.521E+08	1.454E+08
18	0	2	25	100	100	29463.0	186.5	1.0	29.9	4.158E+07	1.604E+08	1.531E+08

Figure 2.4-2. ACCRV Operating Weight Conditions

3.0 CHASSIS STRUCTURAL ANALYSIS

3.1 Introduction

A NASTRAN finite element computer model was developed for the ACCRV chassis stress analysis. The finite element model fully represents the main load bearing structure consisting of an aluminum honeycomb sandwich panel, selected for minimum weight, outer shell and its internal bulkheads. Concentrated loads representing major subsystems such as engine, transmission, suspension, etc., are applied at their points of attachment. Static fluid pressure loads were applied as required to simulate water, fuel and agent tank loadings. The remaining vehicle weight is distributed by adjusting the finite element densities representing the vehicle structure. The complete NASTRAN model of the ACCRV structural frame shown in Figure 3.0-1 has 3786 degrees of freedom, with 804 elements and 631 grid points.

Three loading conditions representing the most demanding operating conditions to which the vehicle would be subjected during its lifetime have been investigated. The largest stresses occur under critical hull torsion-bending and vertical impacts. The maximum stress for these cases result in positive margins of safety; they are conservative in that they represent concentrated suspension loads which will be distributed over a larger area by the suspension support brackets. Stresses in areas removed from the concentrated suspension loads are well within acceptable limits for the sandwich material.

The following sections, 3.2 Structural Description, and 3.3 Structural Design Criteria, have been updated from the Phase I Report, Reference 1.

3.2 Structural Description

To minimize weight the selected ACCRV structure is built from a standard off-the-shelf 5052 aluminum honeycomb sandwich panel with sufficient strength and stiffness to support structural loads. Construction is similar to that used by Hexcel on a Honeycomb trailer which resulted in a 28% weight savings over a conventional trailer of identical dimensions, Reference 2. Mechanical property data for the sandwich panel are given in Figure 3.0-2 as taken from Reference 3 and used on portable structures, stages, and shelters. The ACCRV structural panels are assembled using various standard extruded shapes specifically designed to join and close-out the edges. The extrusions are bonded to the sandwich panels by a high performance room temperature cure epoxy adhesive. A typical fabrication using the honeycomb sandwich and joining extrusions is shown in Figure 3.0-3. The possibility of using aluminum planking and composite materials in fabrication of the ACCRV structure will be investigated during Full Scale Development (FSD).

The ACCRV structural arrangement is displayed in Figure 3.0-4. This design makes maximum utilization of load carrying structure by

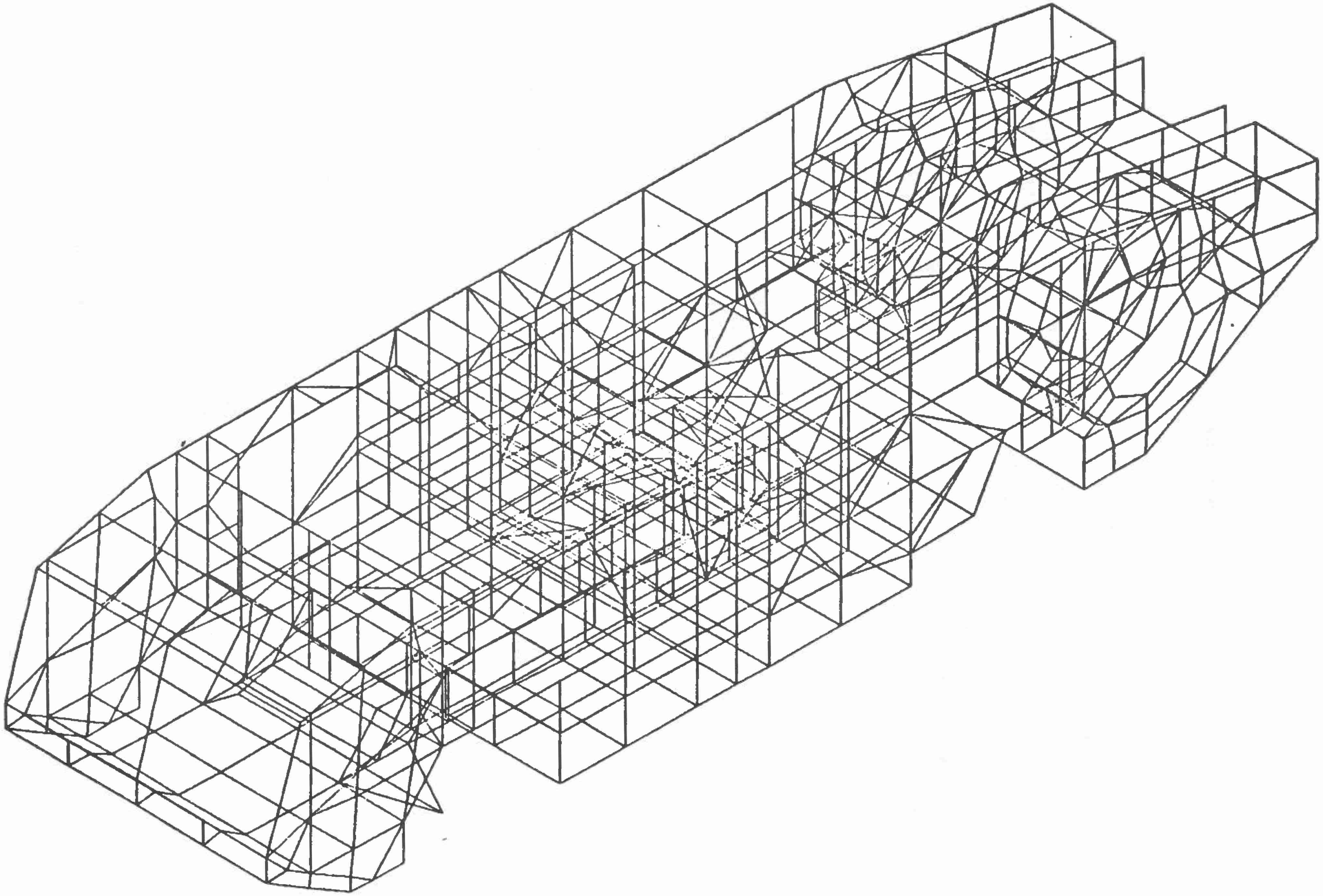


Figure 3.0-1. Complete NASTRAN Model of ACCRV Structure and Frame Subsystem

PROPERTY	TEST	TEST VALUE
Panel Measurements	Thickness	1.004 inch
	Weight	0.92 psf
Flatwise Compressive @ R.T.	Ultimate Stress	330 psi
ASTM C 365 3 x 3	Proportional Limit	333 psi
	Modulus	163 ksi
Beam Flexure 20" Span	Ultimate Load	286 lbs
2" L x 24" W	Proportional Limit	252 lbs
ASTM C 393	Deflection per 10 lbs	0.012 inch
2" W x 24" L	Ultimate Load	297 lbs
	Proportional Limit	199 lbs
	Deflection per 10 lbs	0.014 inch
Edgewise Compressive @ R.T.	Maximum Load	2523 lbs
2" W x 4" L	Maximum Facing Stress	31500 psi
ASTM C 364		
2" L x 4" W	Maximum Load	2383 lbs
	Maximum Facing Stress	29800 psi
Edgewise Flexural	Ultimate Load	822 lbs
2" W x 12" L 8" Span	Proportional Limit	400 lbs
	Deflection per 10 lbs	.0005 inch
2" L x 12" W	Ultimate Load	780 lbs
	Proportional Limit	367 lbs
	Deflection per 10 lbs	.0005 inch
Thermal Expansion 4" W x 30" L	After 2 hrs. @ 120°F	+ .0186"
	After Cooling 2 hrs. @ R.T.	+ .0008"

Figure 3.0-2. Mechanical Property Data 5052 Aluminum Honeycomb Sandwich

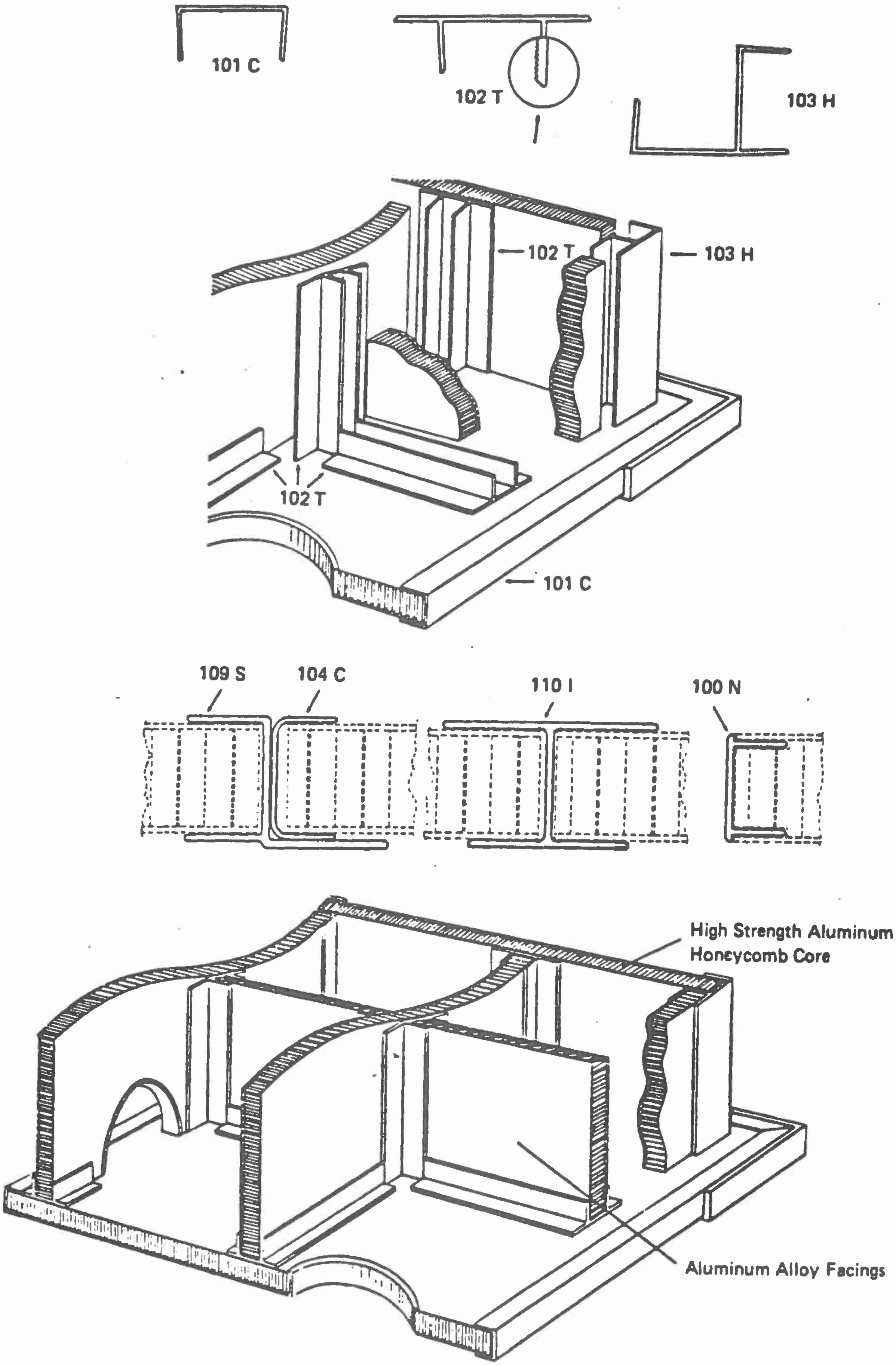


Figure 3.0-3. Typical Sandwich Assembly Technique

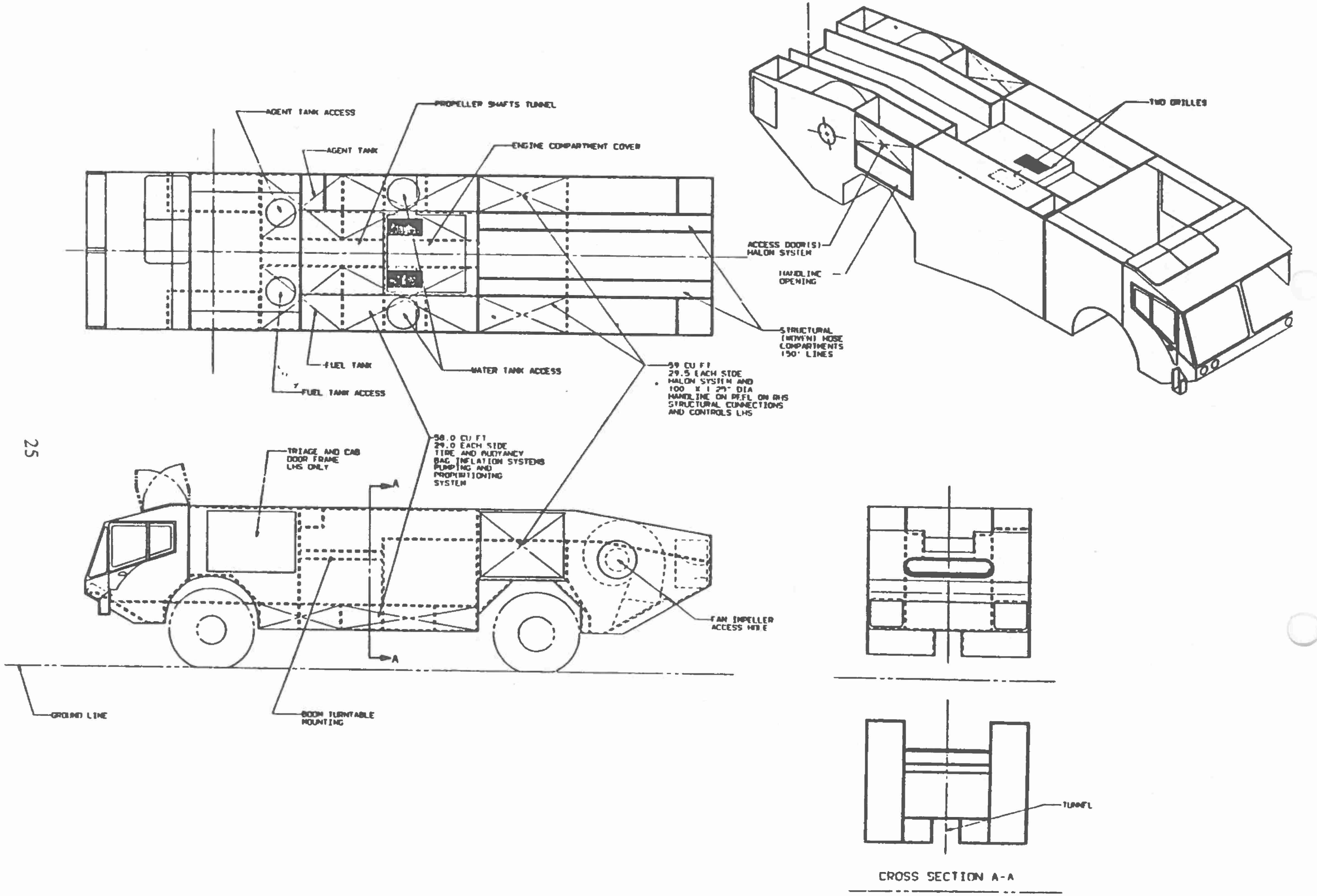


Figure 3.0-4. ACCRV Structural Arrangement

also using the structure for fuel, water and agent tank walls. In addition, the vehicle side walls serve as end closures for the fans. The boom turntable mounts on a panel which receives support on four sides, thus providing for adequate support and load distribution.

Two forward and two aft integral towing/tie-down fittings are provided for securing the vehicle during shipment or towing when disabled. They are positioned adjacent to lateral and longitudinal bulkheads to minimize eccentricity of the towing/tie-down loads. The ACCRV also has internal gussets, bulkheads, floors, fittings and stiffeners which complete the vehicle structure. These items accept the concentrated loads from the engine, transmission, suspension, etc., and distribute them to the primary structure.

3.3 Structural Design Criteria

Structural design criteria establish the guidelines for critical loading conditions, safety factors, etc., and are the foundation of structural analysis. The selected criteria cover all conditions that could be encountered in the vehicle operational spectrum including emergency conditions. A factor of safety is then applied to these loads to ensure that the vehicle structure does not fail under the derived design loads.

3.3.1 Operational Spectrum

The ACCRV shall have the capability of operating on pavement, adverse terrain and water.

A. Pavement

For highway operations the air cushion mechanism is stowed and the ACCRV operates like a conventional truck. Vehicle top speed is 65 mph on level ground.

B. Adverse Terrain and Water

In adverse terrain the vehicle operates with air cushion augmentation, where the track and wheels support up to 30% of the vehicle weight. Adverse terrain is defined as any off road surface such as marsh or soil; any soil or unprepared surface having a CBR of 3.0 or higher; any swamp with or without water; rough terrain, and deep snow and/or ice covered surfaces. Vehicle operation in sheltered bodies of fresh water is limited to sea-state 1 with waves of 1.0 foot maximum height. On level soft surfaces and water with the air cushion deployed, an operating speed of 10 mph shall be used. On rough terrain the vehicle shall be capable of traversing surface irregularities up to +/- 12.0 inches, and 5% side slopes.

3.3.2 General Criteria

The applied loads presented in this section are the maximum loads expected in the operational life of the ACCRV. Under applied loads (limit) the structure shall not deform elastically or plastically to interfere with operation of the vehicle or require frequent replacement or repair. The limiting stress under applied loads corresponds to the 0.2 percent offset yield strength of the material. In addition, all applied loads are multiplied by a safety factor to obtain design loads (ultimate). The safety factor is generally 1.5. Special factors are used where necessary. The structure shall not fail under design loads.

Design Load = Applied Load x Safety Factor

Bell developed the selected criteria based on contract specifications, contractor experience, government publications such as the automotive series handbooks and MIL-Handbook/specs and standard textbooks. Structural computer codes are used to determine internal loads in Section 3.4.

3.3.3 Chassis Design Conditions

The critical design conditions for the chassis are shown in Figures 3.0-5 and 3.0-6. With these parameters and the vehicle weight distribution the shear, moment and torsion along the vehicle length are obtained by computer code. Data are also shown for rotational and translational accelerations which are used to determine local load factors for chassis mounted equipment.

The maximum externally applied loads for normal operation over highway and secondary unpaved roads, without air cushion augmentation, are shown in Figure 3.0-5.

In adverse terrain, the vehicle is mainly supported by an air cushion with the wheels (tires and tracks) supporting only sufficient weight to provide tractive effort and directional control. Maximum externally applied loads for adverse terrain operation are listed in Figure 3.0-6.

Operation over water is limited to sea-state 1 where wave heights are no greater than 12.0 inches trough to trough. Water impact loads on the hull are expected to be insignificant so the landborne design conditions will govern the design. In hullborne operations the chassis and appendages must resist the associated hydrostatic pressures.

3.3.4 Crash Load Factors

Based upon Voyageur and LACV-30 ACV criteria, seat installations and the structural attachments for all items of equipment, failure of which could result in hazard to personnel or crew, shall be designed to withstand loads resulting from the following ultimate inertia load factors, applied separately.

Downward	4.0	Upward	3.0
Forward	6.0	Aft	3.0
Laterally +/-	3.0		

DESIGN CONDITION	VERTICAL LOADS				HORIZONTAL LOADS			
	Z_{LF}	Z_{RF}	Z_{LR}	Z_{RR}	X_{LF}	X_{RF}	X_{LR}	X_{RR}
1.1 Braking - Front Wheels Only n_z=1.0, n_x=.50	.5W	.5W	0	0	.25W	.25W	0	0
1.2 Diagonal Wheels Loaded, with Front Wheel Obstruction n_z=1.5, n_x=.50	1.0W	0	0	.5W	.5W	0	0	0
1.3 Symmetrical Vertical Impact, n_z=2.0	.5W	.5W	.5W	.5W	0	0	0	0
1.4 Unsymmetrical Vertical Impact, N_z=1.0	1.0W	0	0	0	0	0	0	0

W = Vehicle Gross Weight

Figure 3.0-5. Wheel Loads Without Cushion Augmentation - Pavement and Unpaved Roads

DESIGN CONDITION	VERTICAL LOADS				HORIZONTAL LOADS			
	Z_{LF}	Z_{RF}	Z_{LR}	Z_{RR}	X_{LF}	X_{RF}	X_{LR}	X_{RR}
2.1 Wheels Equally Loaded n_z=1.3, n_x=0	.15W	.15W	.15W	.15W	0	0	0	0
2.2 Diagonal Wheels Loaded, with Front Wheel Obstruction n_z=1.75, n_x=.50	.75W	0	0	.30W	.5W	0	0	0
2.3 Unsymmetrical Vertical Impact, n_z=1.3	.60W	0	0	0	0	0	0	0
2.4 Rear Wheels Loaded Only, Tractive Effort n_z=1.3, n_x=.50	0	0	.30W	.30W	0	0	.25W	.25W

Add cushion loading to these conditions

Figure 3.0-6. Wheel Loads with Cushion Augmentation Adverse Terrain

Crash load factors shall in no way preclude the need for compliance with load factors derived from operational design conditions shown in Figures 3.0-5 and 3.0-6.

3.3.5 Skirt Loads

Skirt

The air cushion skirt shall be structurally capable of maintaining a cushion pressure 1.5 times the maximum dynamic operating pressure (P_{max}) at a minimum payload and speed.

Applied Pressure = $1.5\ P_{max}$

Design Pressure = $2.25\ P_{max}$

Skirt Attachments

Design Pressure = $3.0\ P_{max}$

3.3.6 Wheel Loads

Based upon criteria in the automotive handbook series maximum established wheel loads encountered under dynamic loading conditions are given below. See Figure 3.0-7 for wheel load nomenclature. These conditions cover sloped terrain, obstacle impact, braking and uneven terrain operations.

Maximum Wheel Loads

Design Condition	Applied Wheel Load
Fig. 3.0-5	$F_z = 1,0\ W$ $F_y = 0.50\ W$
Fig. 3.0-6	$F_z = 1.0\ W$ $F_x = 0.50\ W$

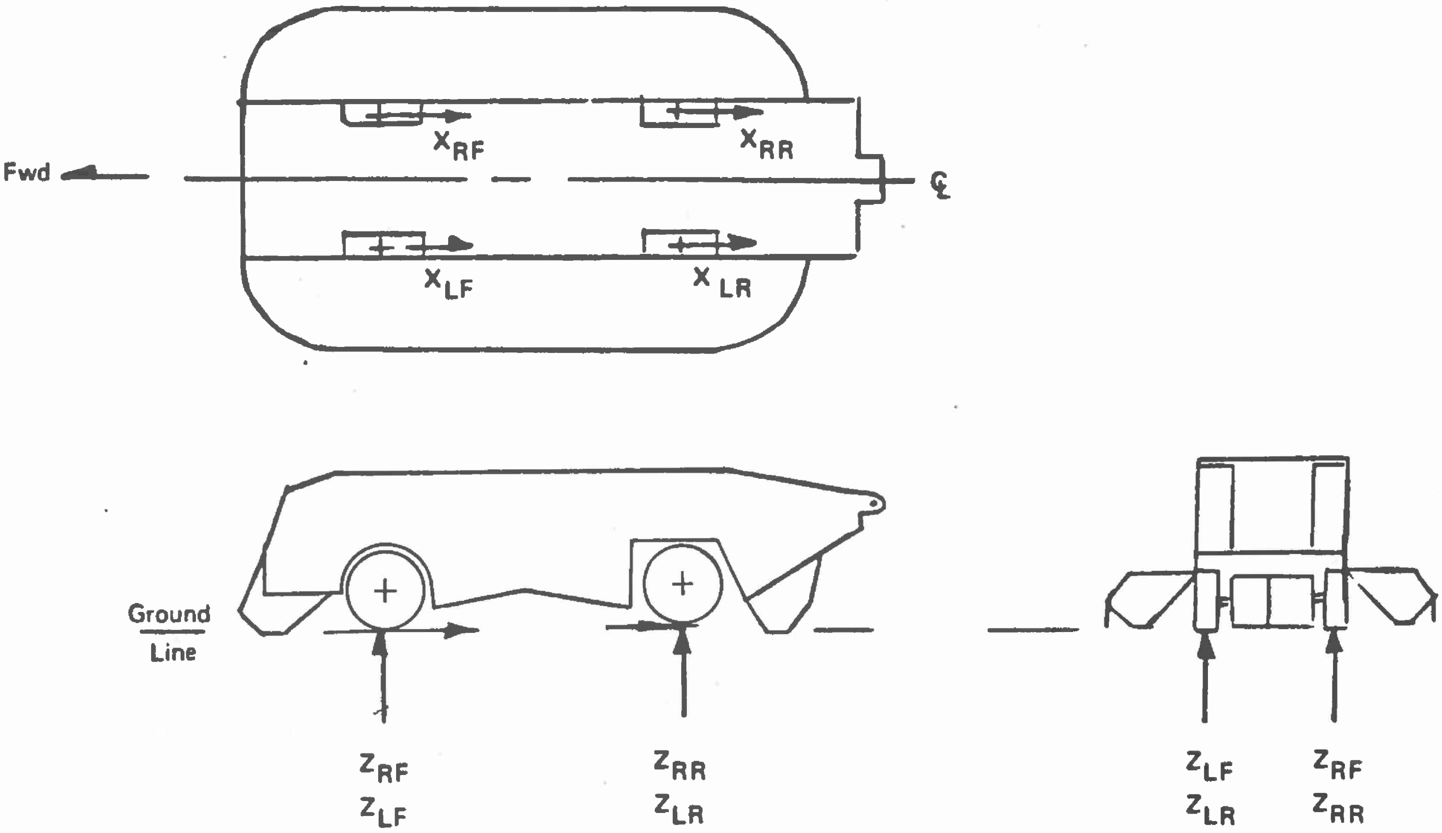
where W = Vehicle Design Weight = 30,000 lb

Design Loads = 2.0 Times Applied Loads

3.3.7 Miscellaneous Criteria

Vehicle Design Gross Weight, W = 30,000 lb

Design Tow Loads: Maximum Apex Angle of Towing Bridle Equal to 60 Deg



X = Longitudinal (Drag)

Z = Vertical

LF = Left Front

RF = Right Front

LR = Left Rear

RR = Right Rear

Figure 3.0-7. Wheel Load Nomenclature

Each Tow Fitting, $F_x = 0.50\ W$

$F_y = 0.25\ W$

(Tow loads are based upon Bell's LVT(X) design criteria. The LVT(X) is an armored amphibious personnel carrier designed under a US Navy contract.)

Paddle Track Loads - TBD (Model Tests)

3.4 NASTRAN Finite Element Model

To ensure basic structural integrity of the ACCRV structure and maintain suitable limits on deflections and stress, a stress analysis was conducted using the NASTRAN general purpose finite element program. A detailed model of the load bearing structure and frame including internal bulkheads, was created on the Bell computer aided design system from assembly drawings stored within that system. Several distinct models were developed and then merged to create the entire structure. Openings for doors, windows, engine, transmission and fan access panels were accounted for in the model. Figures 3.0-1 and 3.0-8 present details of the ACCRV structural model. The completed finite element model has 3786 degrees of freedom, with 804 elements and 631 grid points.

The vehicle weight distribution was determined by using effective element densities which account for the structure and small distributed masses, concentrated loads and applied pressures. The sum of the products of element volume and effective density yielded the weight of the structure and small distributed masses. To this were added, at appropriate grid points, concentrated weights representing all other subsystems (i.e., engine, transmission, crew, passengers, suspension and boom. The subsystem concentrated weights were assigned to grid points which are on or very near the actual mounting structure for the subsystem under consideration. Static fluid pressure loads were applied as required to simulate water, fuel and agent tank loadings. The resulting model had a gross vehicle weight of 30,502 lb.

A total of three critical loading cases were analyzed based upon the structural design criteria developed in Section 3.3. They represent the most demanding operating conditions to which the vehicle would be subjected during its lifetime. Dynamic suspension loads were represented by an equivalent static load as presented in Section 3.3. The operational conditions considered were the following:

- **LOADING CONDITION 1: SUSPENSION SYSTEM LOADS**

  A 2 "g" vertical acceleration is applied to the model suspension system at gross vehicle weight. The load is applied to the hull by rigid elements representing the vehicle suspension system.

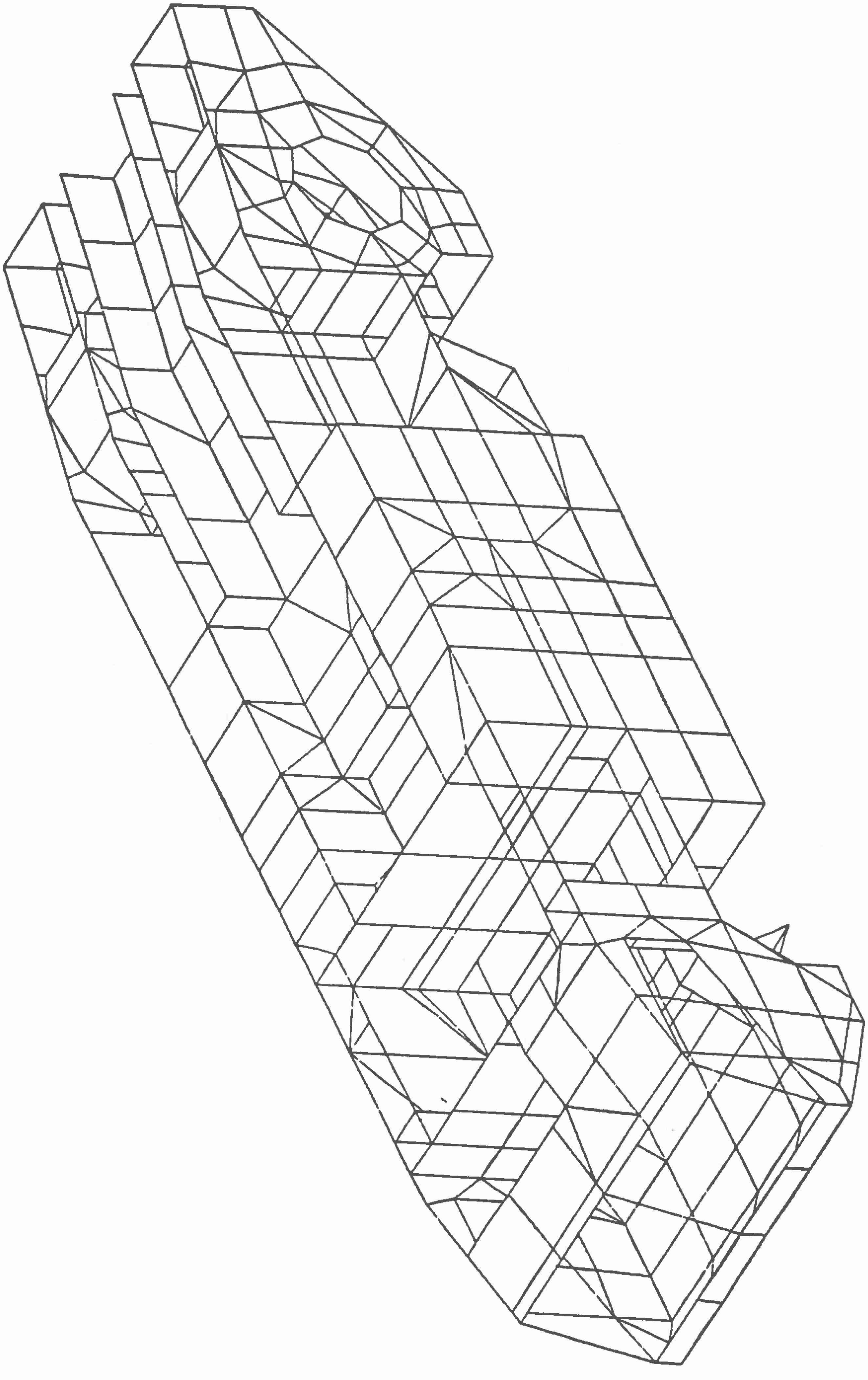


Figure 3.0-8. ACCRV NASTRAN Model Isometric View

- **LOADING CONDITION 2: CRITICAL HULL TORSION/BENDING**

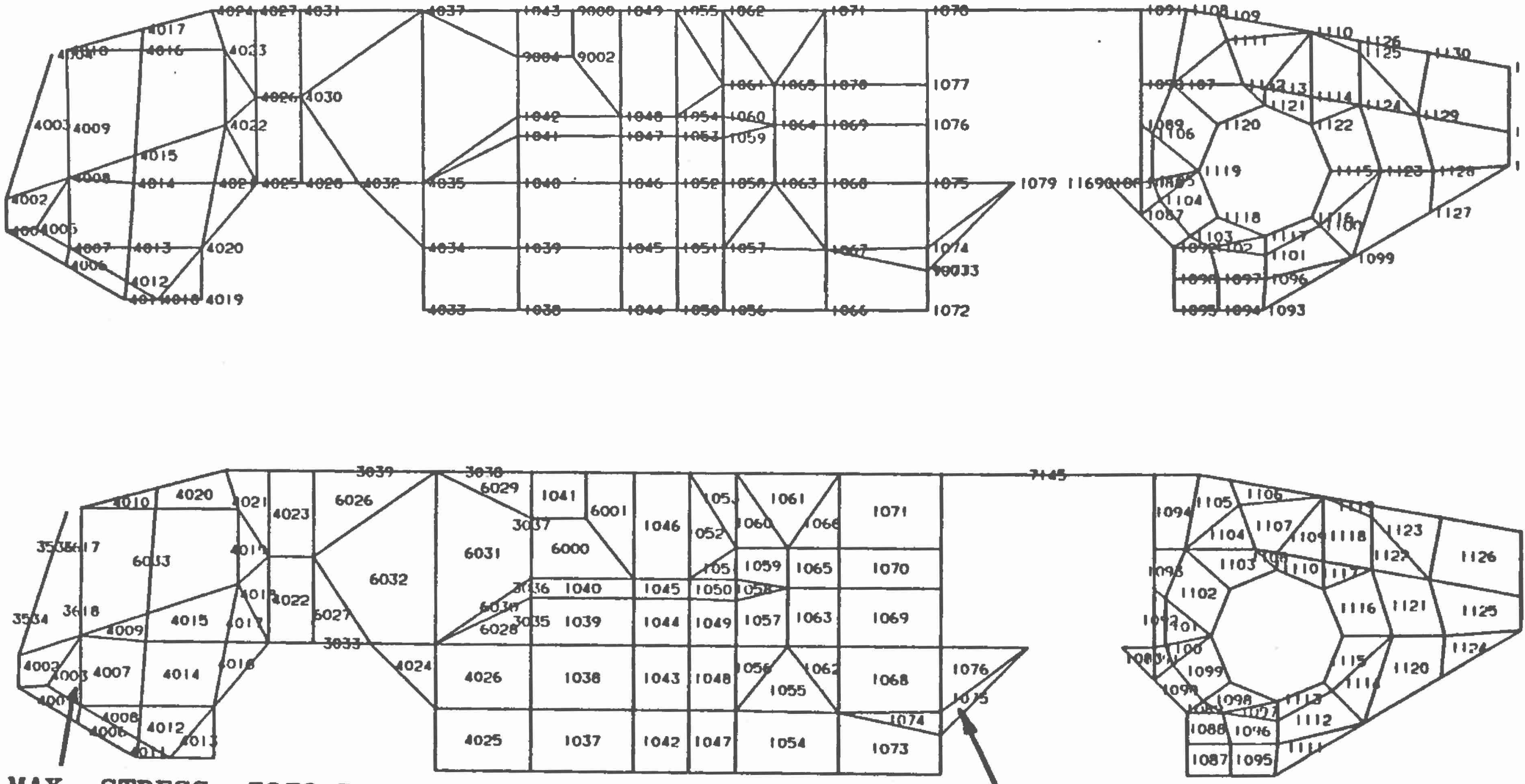
  The model is subjected to a 1 "g" vertical impact on one front tire in the gross vehicle weight condition to create a critical hull torsion-bending situation.

- **LOADING CONDITION 3: HANDLING LOADS**

  A 2 "g" force was applied to the front tow fittings located on both sides of the cab.

For each loading case the deflection patterns, distortion, stress levels and stress gradients were examined. In general overall chassis stress levels are very low and distortions in critical regions like doors and windows are minimal. The largest stresses are presented in Figures 3.0-9 and 3.0-10, for the three critical loading conditions considered. In all cases these stresses occur at points of concentrated load application such as tow fittings and suspension attachments. During the detail design phase these local stresses will be lowered by designing suspension and tow fitting attachments to distribute the induced loads over a larger area. In chassis structure away from concentrated loads, stress levels peaked at 9,000 psi and were generally less than 4,000 psi. This corresponds to test results obtained by Hexcel on the similarly constructed trailer at the Trailmobile Test Center in Cincinnatti, Ohio, Reference 2. In this case the only flexing noted during a standard test sequence (including braking, sharp turns, jack knifing, 8 inch ramp and 6 inch block tests) was in the suspension springs, with only a few chassis strain gases recording any stress. This high rigidity indicated by the trailer tests and ACCRV analysis is attributed to a "unibody" design that distributes loads throughout the structure as opposed to a typical frame and non-structural shell.

A summary of ultimate margins of safety is presented in Figure 3.0-11. As indicated all margins of safety are positive with high margins in all areas away from points of applied concentrated loads. An examination of relative chassis deflections indicates no problems due to vehicle flexing which would cause window cracks, fuel tank leaks, agent tank leaks or separation of door seals.



MAX. STRESS, 7879 PSI
FOR LOAD CONDITION 3

MAX. STRESS, 17,460 PSI
FOR LOAD CONDITION 1

Figure 3.0-9. ACCRV Maximum Stressed Elements, Conditions 1 and 3

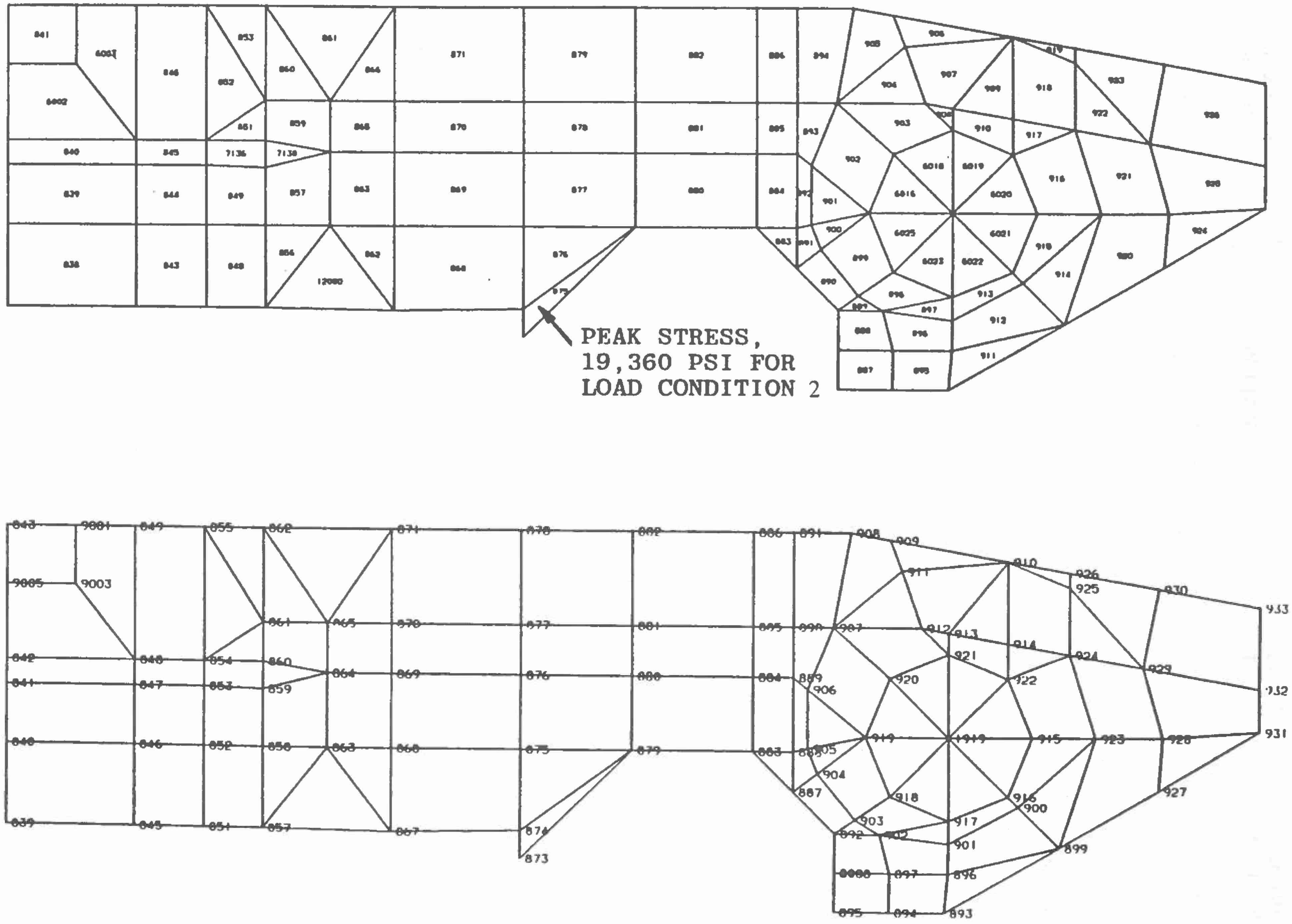


Figure 3.0-10. ACCRV Maximum Stressed Location, Condition 2

LOADING CONDITION	PEAK STRESS (PSI)	LOCATION	ULTIMATE M.S.*
2 "g" Vertical Acceleration	17,460	Rear Suspension Attachment Point	0.18
	8,900	Chassis EL #844	1.32
Critical Chassis Torsion-Bending	19,360	Rear Wheel Well	0.07
	4,200	Chassis EL #1040	3.92
Handling (Towing)	7,873	Front Cab at Tow Fitting	1.63
	4,000	Chassis EL #846	4.17

Figure 3.0-11. ACCRV Margins of Safety

4.0 AIR CUSHION SUBSYSTEM

The air cushion (or lift) system is formed of a peripheral array of open fingers defining an air cusion 28.67 ft. long x 15.0 ft. wide. At 30,000 lbs. weight, the cushion pressure is 71.5 psf. Two 24 inch diameter lift fans supply 900 cfs airflow when running at 3400 rpm. This airflow provides an effective air gap of 0.92 in.; the resulting gap-to-beam ratio of 0.005 is characteristic of rough surface, moderate speed ACVs. The air cushion subsystem is shown in Figure 4.0-1.

4.1 Skirts and Deployment/Retraction

The ACCRV skirt type selected is the open full depth finger as shown in Figure 4.1-1. The knuckle shaped finger was chosen because it provides the most cushion area for a given structural overhang. A 43 degree angle between the lower finger face and the ground plane provides sufficient static pitch and roll stiffness without the use of cushion divider seals. Finger attachment will be by batten strips bolted to the chassis (front and rear) and to the hinged side panels. Full depth fingers are relatively simple to manufacture, although six separate patterns are required for the front, rear, corners, sides, front wheel area, and transition fingers. All fingers are approximately 20 inches wide at the outer face. Small air lubrication holes may have to be cut in the lower face of the fingers to augment the heave stability. The fingers will be made without holes initially; holes will be cut on the prototype vehicle as required. Although this will increase the finger wear rate overland, it is a practical solution to the heave instability, should it actually occur. A second method would be to employ a system for actively controlling the heave, if required. This would be more complex and more expensive.

Due to the (relatively) small size of the fingers and the low cushion pressure of the ACCRV, the material strength requirements are very low (5 lb/inch face tension for example). Finger material selection in this case can be made more on the basis of wear resistance (thickness of rubber outer layers), or price and availability. Skirt material with weights in the 40-45 oz/yd range is appropriate for the ACCRV.

A spray suppression skirt will also be used, extending all around the cushion perimeter and from the upper finger attachment down to the on-cushion water line. It will be a single thickness sheet made in sections. It will attach to the ACCRV with battens and will have a light chain sewn into the hem-pocket all around the bottom edge to stabilize the skirt. (The spray skirt can be an optional inflatable buoyancy bag on each side, if required.)

Skirt deployment/retraction involves two processes; one is the rotation of the full length side panel as shown in Figure 4.1.1 and the second is the operation of the cable/winch system restraining the fingers as shown in Figure 4.1-2. The side panels are driven by four hydraulic actuators on each side; the winches at the front, back, and each side are driven by electric motors. The spray skirt is stowed flat against the re-

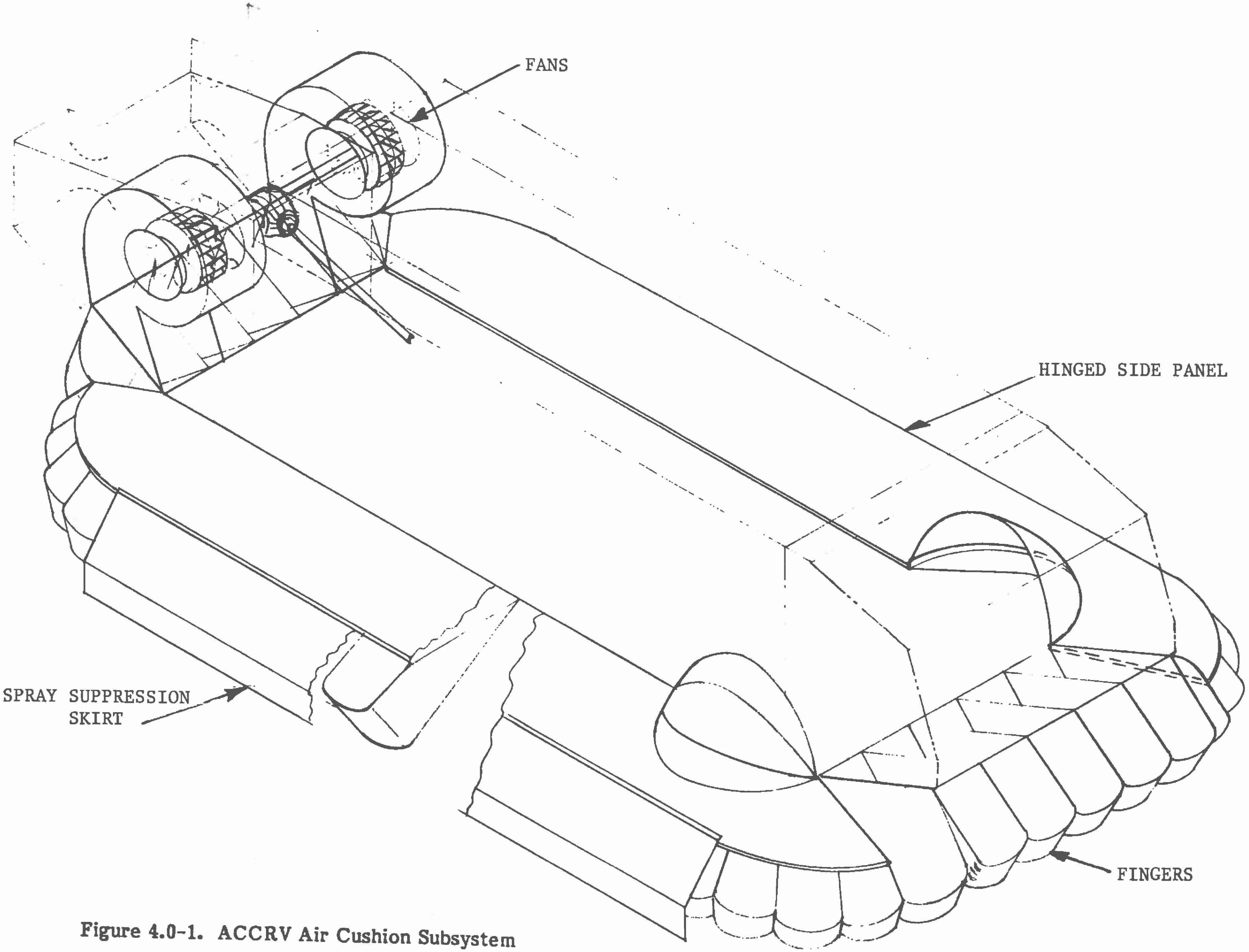


Figure 4.0-1. ACCRV Air Cushion Subsystem

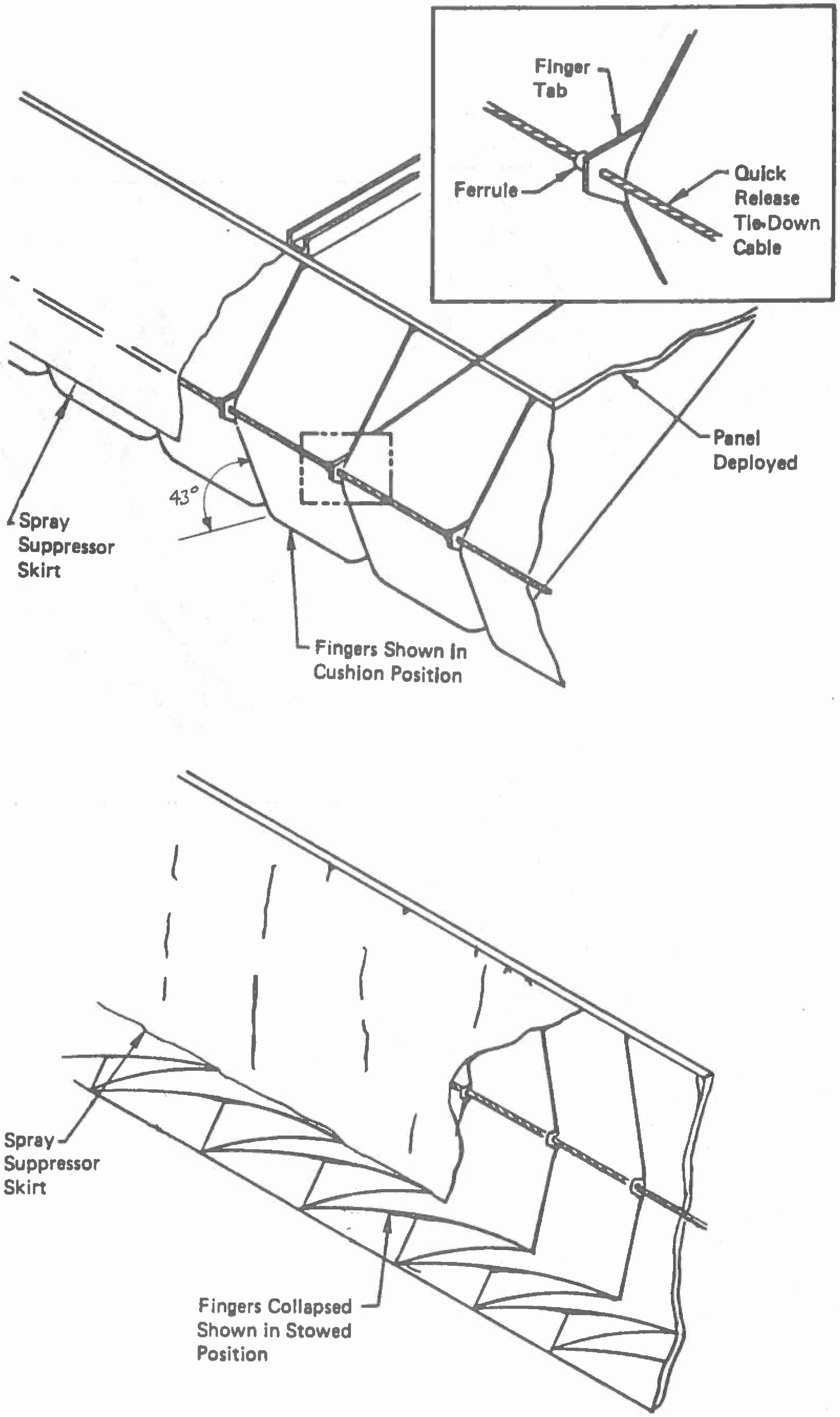
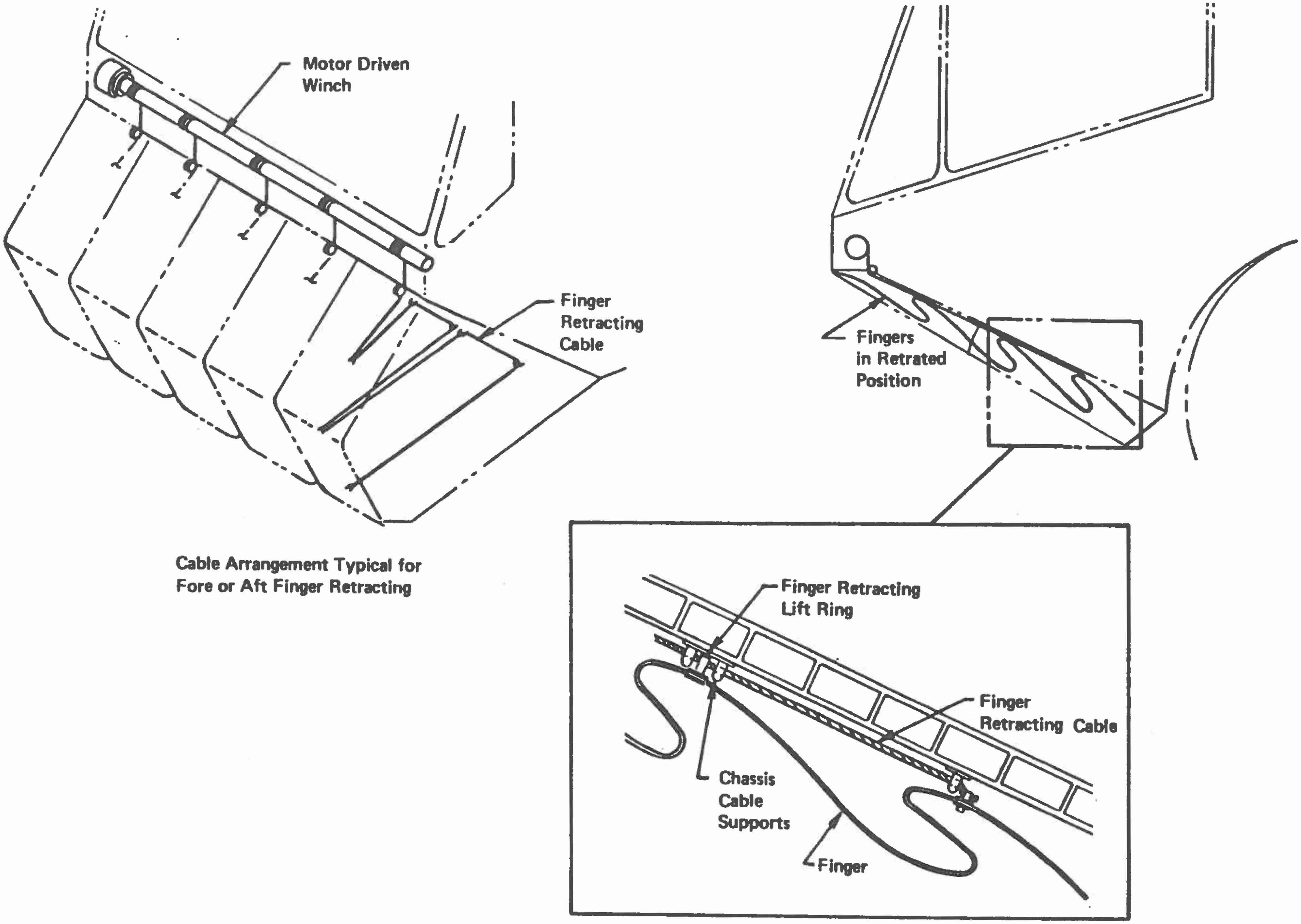


Figure 4.1-1. Side Finger Stowage



Cable Arrangement Typical for Fore or Aft Finger Retracting

Figure 4.1-2. Typical Front or Rear Skirt Retraction tracted fingers using elastic tie down straps which are stretched and hooked into position automatically.

Skirt effects on heave stability, pitch and roll stiffness overland, and drag overwater versus speed, have been discussed previously in R&D Design Evaluation Report No. 7646-927001. In that report the ACCRV was found to be unstable in heave, but addition of stabilizing air holes in the lower face of the fingers will preclude any heave instability. The selected finger design was also shown to have adequate pitch and roll stiffness to provide sufficient dynamic stability while underway.

4.2 Air Cushion Fans and Cushion Powering

The lift fan selected for the ACCRV is a 24 inch diameter double-width, double inlet, backward curved airfoil centrifugal fan. It is aerodynamically and mechanically similar to the 30 inch diameter Bell type A1 fan used in the Bell-Halter BH-48 Hydrographic Survey Boat "Rodolf". See Figure 4.2-1.

The fan impeller is of all aluminum welded construction, comprised of machined center disk and outer shrouds, and extruded symmetric airfoil blades. Steel shafts are bolted to either side of the center disk and run in bearings partially submerged in the inlets to minimize installed width. The single discharge volute housing is also of welded aluminum construction. Two of these fans are used on the ACCRV, mounted on each side above and to the rear of the rear tires.

Based on the lift system requirements, the nominal fan design point for each fan is 90 psf and 450 cfs running at 3400 rpm. To maintain the cushion pressure during transmission shifts, the minimum fan speed of 2750 rpm must be maintained at an engine speed of 1617 rpm after each upshift. This gives a gear ratio of 1:1.7. This results in the fan operating over a range of rpm from 2750 to 3910 as the engine rpm varies from 1620 to 2300. The horsepower required by the two fans varies from 105 hp at 2750 rpm to 230 hp at 3400 rpm, and to 360 hp at 3910 rpm.

Curves of pressure, flow, and horsepower for various fan rpm is called a fan map. Fan maps are calculated from the fan dimensions and non-dimensional coefficients for pressure and flow, and the efficiency, as follows;

$$P_s = \psi_s \rho U_2^2 \qquad (1)$$

$$Q = \phi \pi D_2 B_2 U_2 \qquad (2)$$

$$HP = \frac{P_s Q}{550 \eta_s} \qquad (3)$$

where P_s = fan static pressure - psf

ψ_s = fan static pressure coefficient

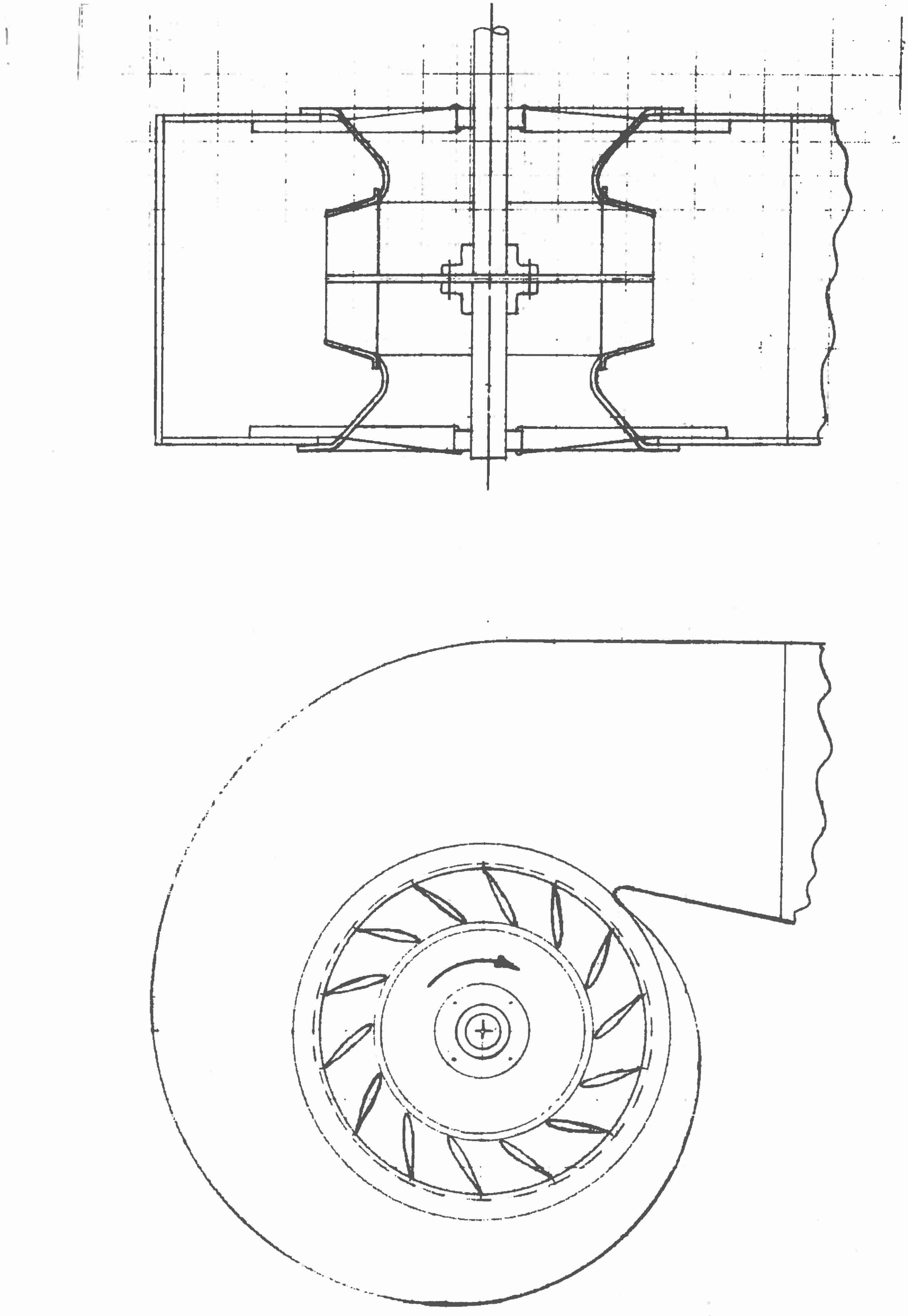


Figure 4.2-1. ACCRV Lift Fan

ρ = air density - slug/cu.ft.

U_2 = tip speed - ft./sec. = D rpm/60

Q = volume flow rate - cu.ft./sec

ϕ = flow coefficient

D_2 = impeller outside diameter - ft.

B_2 = blade span at D - ft.

HP = horsepower

η_s = static efficiency

Figure 4.2-2 shows the map of pressure and horsepower curves versus flow for the 24 inch diameter fan selected for the ACCRV.

Fan power is taken from the front of the engine crankshaft through a clutch, shaft with couplings, to a step-up "T" gearbox. The clutch is a centrifugal Sprague type which allows the fan to freewheel when engine speed drops suddenly, thus preventing large torsional transients in the fan drive during the transmission shift sequence.

4.3 Feed System Losses

The air cushion feed system is comprised of the fan inlet duct and the fans themselves, and the discharge ducts to the cushion. Pressure losses arise from friction, turns (bends), and expansion or contraction of the airflow. Pressure losses were calculated based on Ref. 4 for the friction loss, Ref. 5 and 6 for the bend loss, and on Refs. 4 and 7 for the expansion/contraction loss.

The calculated losses are listed in Table 4-1. Each term shown is the loss (or rise) in pressure for a nominal 900 cu.ft./sec airflow. It was assumed that both the inner and outer sections of each double width fan suffered the inlet losses shown. The feed system loss is represented in Figure 4.2-2 by the difference in the P_{FAN} and $P_{CUSHION}$ curves.

4.4 Ride Quality Assessment

The ride quality of the ACCRV while operating on land will be better than the P-19 because although many of the suspension components are simular to those used in the P-19, the component characteristics will be tuned or adjusted to achieve better ride quality, even when off-cushion. For operation overwater, the primary consideration in ride quality assessment is the vertical (heave) vibration environment in occupied areas. The response of the ACV when riding over water waves is compared to vibration criteria for various durations and types of situations, i.e., resting, working, emergency, etc.

The heave frequency and damping ratio of the ACCRV were calculated first. Then the response of the craft was computed going over 1

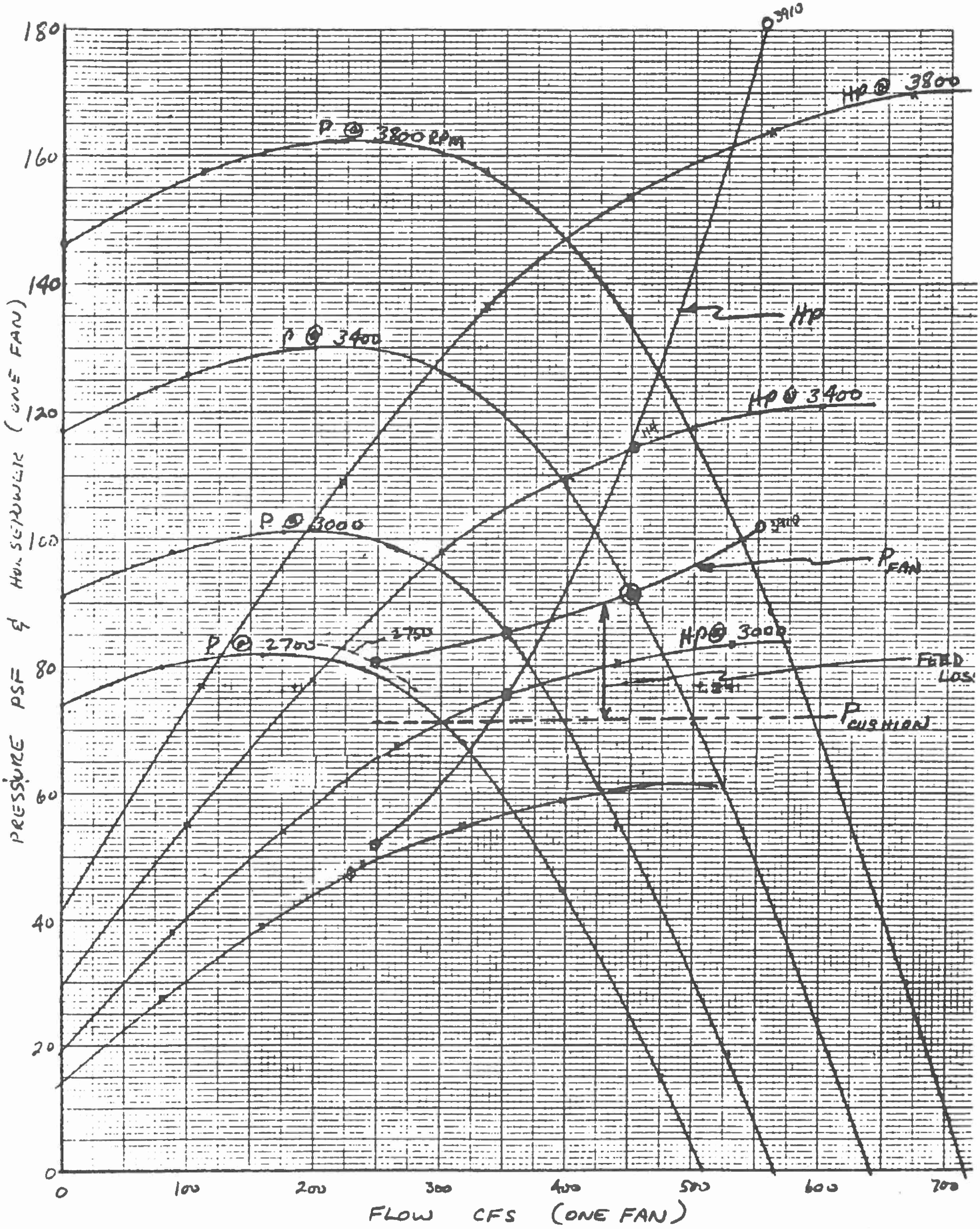


Figure 4.2-2. Twenty-four inch Diameter ACCRV Fan Curves

foot waves at several speeds. These vibration levels were then compared to previously established criteria.

TABLE 4.1 LIFT SYSTEM SUMMARY OF PRESSURE LOSSES AT DESIGN FLOW

TYPE OF LOSS		ΔP (psf)	
10% Entry Loss at Rear Inlet		3.13	
Inlet Duct Friction		2.51	
Inlet Duct Expansion		1.59	
90 degree Turn Into Inlet of Fan		5.92	
Expansion in Fan Discharge		3.14	
Friction in Fan Discharge		0.77	
70 degree Turn into Cushion		5.15	
	TOTAL		22.21
Pressure Recovery in Fan Discharge		5.29	
	TOTAL		16.92

Heave frequency is given by Ref. 5, Eqn. 107;

$$f_n = \frac{1}{2\pi} \sqrt{\frac{S\, P_c g}{h\, w}} \tag{4}$$

where		ACCRV Value
	f_n = heave frequency Hz	
	S = cushion area, sq.ft.	420
	P_c = cushion pressure, psf	71.5
	g = acceleration of gravity, ft./sq.sec.	32.2
	h = cushion depth, ft.	2.67
	w = weight, lb.	30,000

$$f_n = \frac{3.47}{2\pi} \text{ rad/sec} = 0.553 \text{ Hz}$$

Magnification ratios have been measured for small models and indicate an average damping ratio, ρ , of 0.15.

The effective wave amplitude is given by Eqn. 104, Ref. 5;

$$F \frac{L}{\lambda} = \left| \frac{\sin \frac{\pi L}{\lambda}}{\frac{\pi L}{\lambda}} \right| \qquad (5)$$

For L = 28.67 feet (length at craft fingers), and the wavelength, λ, for 1 foot waves = 21 feet , so that

$$F(\frac{L}{\lambda}) = \left| \frac{\sin (4.2890)}{4.2890} \right| = 0.2126 \text{ for } L/\lambda = 1.365$$

The wave encounter frequency, W, at 8 mph is given by

$$W = \frac{2\pi \ (V + V_w)}{\lambda} = \frac{2\pi \ (11.73 + 8.5)}{21.0} = 6.05 \text{ rad/sec} \qquad (6)$$

where V = ACCRV speed in ft/sec

V_w = Wave crest speed in ft/sec

This results in a frequency ratio, W/W_n, of $6.05/(0.553 \times 2\pi) = 1.741$, indicating that the 8 mph wave encounter frequency is above the natural frequency in heave. The magnification factor, M, is given by:

$$M = \frac{1}{\sqrt{\left| 1 = \frac{W}{W_n}^2 \right|^2 + \left| 2\rho \frac{W}{W_n} \right|^2}} \qquad (7)$$

Substituting $W/W_n = 1.741$ and $= 0.15$ from above, $M = 0.4768$. Thus, the hull response will be (1 ft) x (0.2126) x (0.4768) = 0.101 ft. For harmonic motion the acceleration will be

$$\begin{aligned} a &= 0.05113 \text{ (inch pk-pk)(cps}^2) \\ &= (0.05113)(0.1011 \times 12) \left(\frac{6.05}{2\pi} \right)^2 \qquad (8) \\ &= 0.0577 \text{ g} \end{aligned}$$

This value is midway between the 24 hour and 4 hour curves for "Fatigue Decreased Proficiency" at 1.8 Hz on Figure 96 of Ref. 8, i.e., this vibration level is acceptable for 10 hours or so without loss of proficiency.

Although the ACCRV ride is quite acceptable at 8 mph in 1 ft waves, the ride will be less comfortable at the slower speed at which the wave encounter frequency matches the heave frequency.

$$V = \frac{W_n \lambda}{2\pi} - V_w = \frac{3.47\ (21)}{2\pi} - 8.5 = 3.1 \text{ ft/sec} \qquad (9)$$

At resonance with damping = 0.15, the magnification factor will be 1/[2(0.15)] = 3.33. The heave response will be (1 ft)(0.2126)(3.33) = 0.708 ft, and the acceleration is;

$$a = 0.05113(0.708)(12)(0.553)^2 = 0.133 \text{ g.}$$

On Figure 96, Ref. 8 this g-level will produce sea-sickness in 10% of the people on board if exposed to this condition for 4 hours. It seems unlikely that the ACCRV would need to be operated at this low speed for anything more than a few minutes at a time.

The ride quality of the ACCRV will be quite acceptable for long periods at speeds of 8 mph and further improve at speeds of 10 mph.

5.0 PROPULSION

The Bell ACCRV design integrates the benefits of wheeled-vehicle operation on improved roadways, runways and hard ground and the best type of tracked-vehicle performance in extreme soft-soil conditions. Providing an improved soft ground performance follows the approach of reducing external rolling resistance by reducing sinkage of the running gear, while maintaining an adequate level of positive drawbar pull.

Two modes of operation are incorporated: wheelborne and hybrid. For surfaces such as roads and firm ground, the ACCRV will not usually need its air cushion capability and the skirts and paddletracks will be retracted. Hybrid operations will be conducted over water and soft surfaces, such as marsh, mud, soft sand, and deep powdered snow with the air cushion deployed and the paddletracks providing the propulsive effort.

5.1 Wheelborne

The ACCRV design retains the proven concepts of existing crash rescue vehicles (particularly the P-19). Thus, for operation on highways, roads or natural, hard surfaces, the ACCRV propulsion is much the same as any conventional, all-wheel drive vehicle. Calculating the performance of the vehicle as an all-wheel drive vehicle on hard surfaces is quite readily derived from considerations of weight, engine power, gear ratios, running gear geometry and resisting forces.

5.2 Hybrid

In the hybrid mode of operation, a significant proportion of the ACCRV weight is carried by the lift of its air cushion, and the vehicle is propelled by the thrust of its propulsion unit. The propulsion unit is either tires or a hydraulically actuated paddletrack system, located on the trailing arm-rear axle sub-assembly, and powered, via a hydraulic clutch and chain, by a drive from the differential subassembly.

On water and marginal terrain, the plenum chamber, confined by the flexible skirt around the perimeter of the vehicle, will provide the buoyancy necessary for surface travel. For vehicle propulsion over soft soil, the air cushion is deployed to reduce the vehicle footprint and the paddletrack is used as a means of augmenting the propulsive forces developed by the tires.

5.2.1 Paddletrack

The paddletrack unit, selected in a trade-off study, is comprised of two tracks, 20 inches wide with 60 inches ground contact length. They are accommodated in a trailing arm arrangement, in the under-chassis space bounded by the differential and the rear axle, in-board of the rear wheels. Either aluminum or rubber tracks can be used in the paddletrack configuration. Each material type has advantages and disadvantages. Paddletrack drive is accomplished, via a hydraulic clutch and a drive sprocket located on the rear axle. Intermediate, beam mounted idler wheels, or rollers, are placed between the main driving and idler sprockets to improve the load distribution on the ground. Vehicle mobility is further enhanced by the use of a track tensioner, located on the forward idler, to reduce motion resistance, caused by track caternary sinkage, on marginal terrain. The possibility of relocating the paddletracks to the middle of the vehicle nearer the C.G., with hydrostatic drive, will be investigated in FSD.

For normal wheelborne operations, the tracks will be declutched and retracted. Whenever the vehicle goes into a hybrid mode of operation the paddletrack is deployed, as illustrated in Figures 5.2.1-1 and 5.2.1-2.

The procedure to deploy the paddletrack is as follows: the bogey cylinder (c) is retracted hydraulically; actuator (A) is then charged with air; this action deploys the track assembly, which pivots about (b).

Retraction of the assembly, associated with a vehicle wheelborne mode, is essentially the reverse of the deployment process. Actuator (A) is relieved, causing the assembly to retract, while pivoting about (B). Cylinder (C) is then actuated which causes the pivoting of the front of the bogey beam downwards, about (D). The assembly continues to be retracted vertically until contact is made with snubber (E). The entire assembly then pivots about the differential (F) until the track is parallel to the ground surface, creating a 9.3 inch running clearance when wheelborne. Retraction ceases with the activation of a limit sensor in the hydraulic system associated with actuator (A).

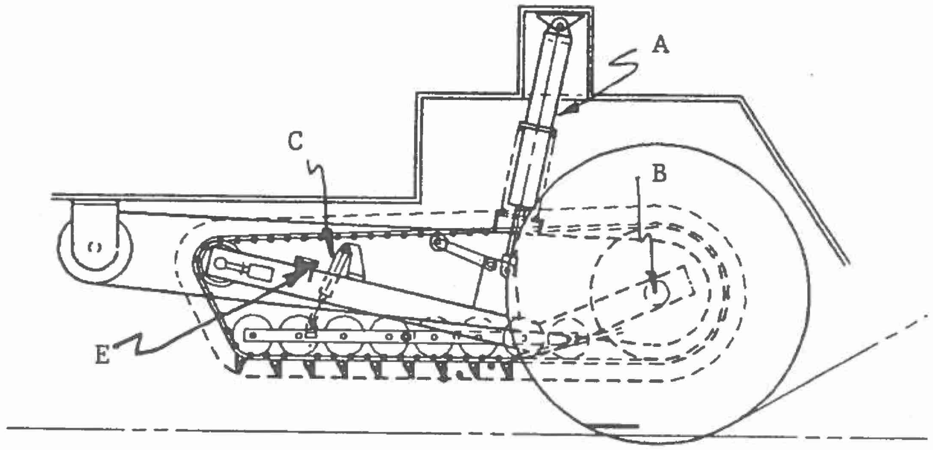
To facilitate loading into a C-130 airplane, the track must be further manipulated to achieve ramp clearance. The vehicle would already be in the wheelborne mode. All that is necessary is to retract cylinder (C) to pivot the front of the bogey beam upward about (D).

5.2.2 Performance Over Water

Various types of propulsors were considered for over water propulsion, but in order to make a smooth transition to soft surfaces the selection settled on paddletracks as providing the best performance choice within the packaging constraints.

Analysis shows that two 20 inch wide paddletracks, powered by 280 HP will develop sufficient thrust to attain a craft speed of 10 mph over water. The upper limit of thrust was derived using the Momentum Equation, shown by Rankine (1865) and Saunders (1957) to hold for a non-ventilating propulsor. Ventilation effects, common in paddlewheels, are minimized over the length of the paddle track. i.e. the fluid entrainment rate is sufficient to completely replenish the depression.

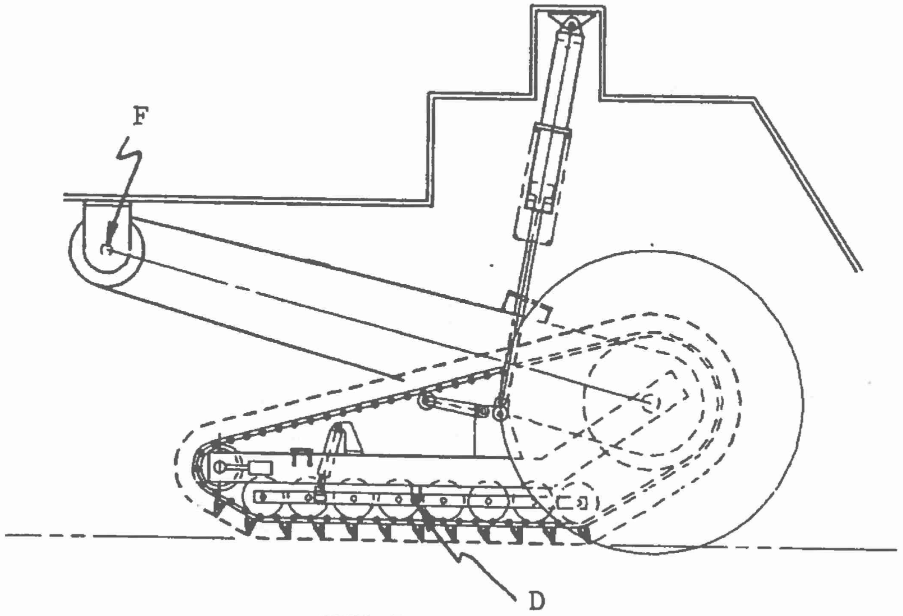
A cleat depth of 3 inches was found to be sufficient to meet vehicle requirements, at the given track speed (Figure 5.2.2-2). The consequent paddletrack thrust, superimposed on the ACCRV drag curves is pre-



WHEELBORNE MODE

DEPLOYMENT

- BOGEY CYLINDER (C) IS RETRACTED
- ACTUATOR (A) IS CHARGED WITH AIR
- TRACK PIVOTS ABOUT (B) UNTIL CONTACT IS MADE WITH THE GROUND
- VEHICLE IS NOW IN HYBRID MODE

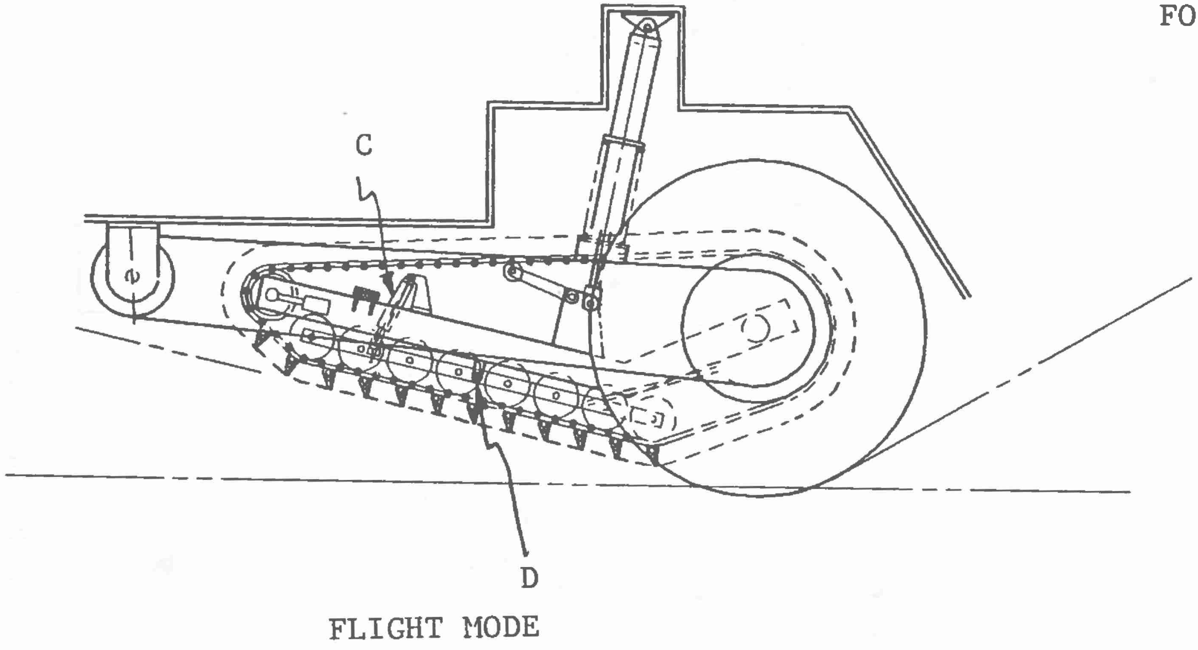


HYBRID MODE

RETRACTION

- ACTUATOR (A) IS RELIEVED
- THE ASSEMBLY RETRACTS, PIVOTING ABOUT (B)
- CYLINDER (C) IS ACTUATED
- THE FRONT OF THE BOGEY BEAM PIVOTS DOWNWARDS ABOUT (D)
- THE ASSEMBLY CONTINUES TO BE RETRACTED VERTICALLY UNTIL CONTACT IS MADE WITH SNUBBER (E)
- THE ENTIRE ASSEMBLY THEN PIVOTS ABOUT THE DIFFERENTIAL (F) UNTIL THE TRACK IS PARALLEL TO THE GROUND

Figure 5.2.1-1. Paddletrack Deployment/Retraction



FOR C-130 LOADING

- VEHICLE WILL INITIALLY BE IN THE WHEELBORNE MODE
- RETRACT CYLINDER (C) TO PIVOT THE FRONT OF THE BOGEY BEAM UPWARDS ABOUT (D)

Figure 5.2.1-1. Paddletrack Deployment/Retraction (Concluded)

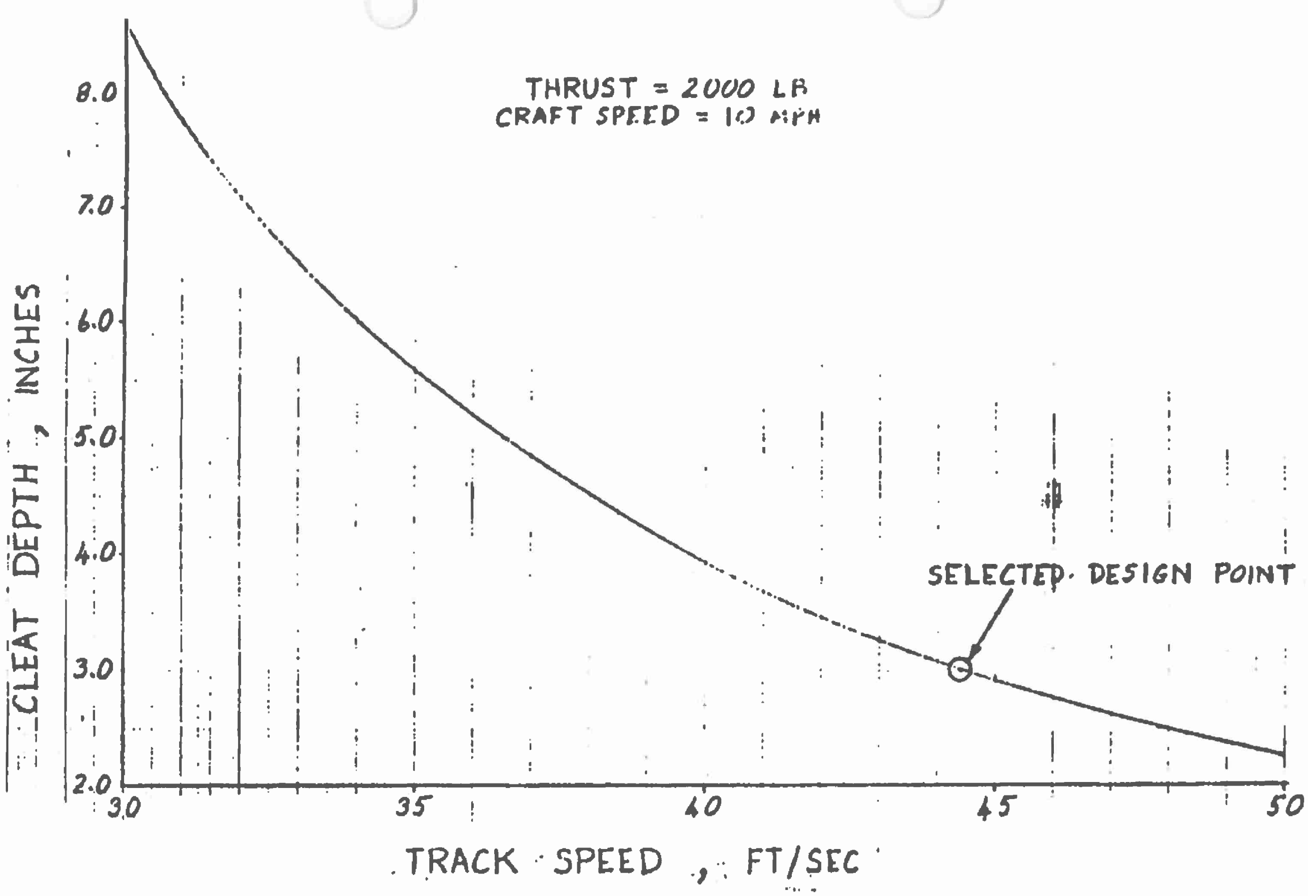
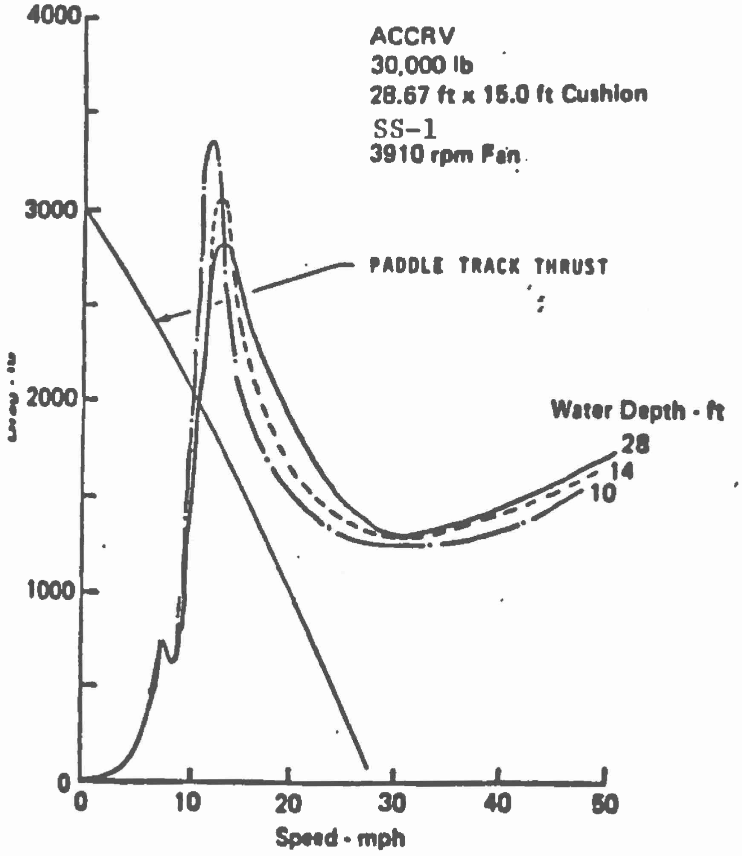


Figure 5.2.2-1. Cleat Depth versus Track Speed



DUAL PADDLE TRACKS:

23" PITCH DIA. SPROCKET/
3" CLEATED TRACK LUGS -
20" WIDE.

POWER - 280 HP AT THE
SPROCKET

SHALLOW WATER, SEA STATE 1

- ACCRV HAS A PREDICTED MAX. SPEED OF 10 MPH ON WATER

Figure 5.2.2-2. ACCRV - Water Performance sented in Figure 5.2.2-2.

5.2.3. Performance On Land In Wheeled and Hybrid Mode

The air cushion assist will provide improved performance over very soft surfaces such as marsh, mud, loose soft sand and deep powdered snow. The criterion for hybrid operation is wheel sinkage. The wheels will sink further into a soft surface when the load is increased. This increased load will increase traction but the deeper sinkage will result in greater resistance to motion. On certain soft surfaces the resistance will increase faster than the tractive effort and at a particular load, resistance will exceed traction and forward motion will not be possible.

For a typical tire, as load is increased, it is necessary to increase the pressure such that the tire footprint (on a hard surface) is maintained approximately constant. This is mandated by the manufacturers to prevent carcass slipping on the rim or being damaged by excessive deflection. Some increase may be permitted at low pressure and very low speed, but essentially the tractive effort (friction and shear) tends to be proportional to this fixed footprint area. Thus, the only way to improve soft surface wheeled propulsion is to increase the total footprint area (by having larger wheels or more wheels) until the vehicle can be sustained on the given soft surface with acceptably low sinkage.

The wheeled tractive effort can be made more effective on a given soft surface by using the air cushion to support an appropriate proportion of the weight and a low wheel load to avoid excessive sinkage and wheel resistance. The air cushion offers no significant resistance to forward motion.

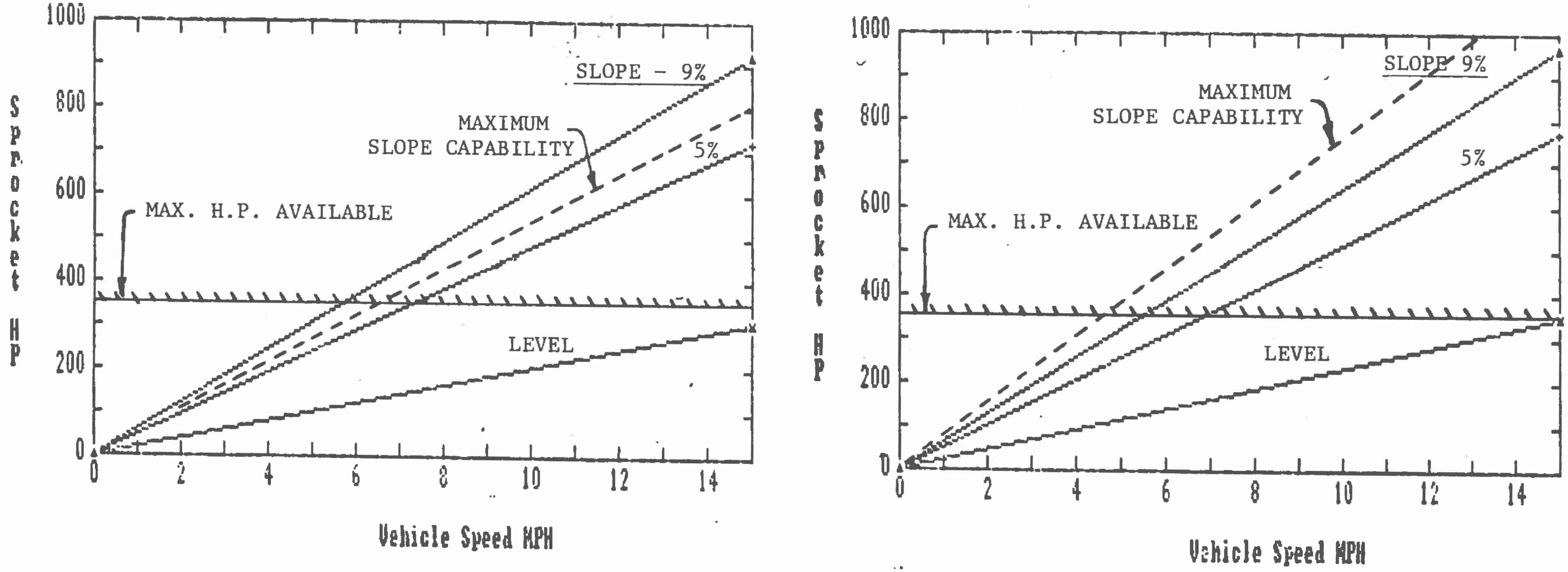
The ACCRV concept combines air cushion performance with that of a tracked vehicle to overcome extreme soft-soil conditions. In hybrid mode the wheel/paddletrack is deployed until sufficient tractive force is developed for vehicle motion. Motion resistance is reduced by retracting the forward wheels, and is an optional feature to be investigated during FSD.

Predicted ACCRV performance on soil with an estimated California Bearing Ratio (CBR) of 3 is presented in Figures 5.2.2-3 and 5.2.2-4. The analysis was conducted using the properties of a fine grain (clay) soil and a coarse grain (sandy) soil. The former (cohesive soil type) does not exhibit significant frictional resistance to shear stress but derives its strength primarily from cohesion. Whereas the latter is a frictional-type soil.

The maximum speed of the vehicle over level ground (CBR=3), in hybrid mode, was found to be 15 mph. This speed would reduce to 7 mph on a 5% forward grade. The vehicle will have a turn capability on such terrain, given adequate turn radii and appropriate turn speeds.

Figure 5.2.2-5 presents the predicted vehicle performance in snow with front wheels retracted. The maximum speed of the ACCRV was found to be 9 mph on a level surface, reducing to 5 mph on a 5% forward grade.

(ESTIMATED SOIL CBR = 3)



GRADE ANALYSIS - Fine Grain Soil

GRADE ANALYSIS - Coarse Grain Soil

<u>ON LEVEL GROUND</u>

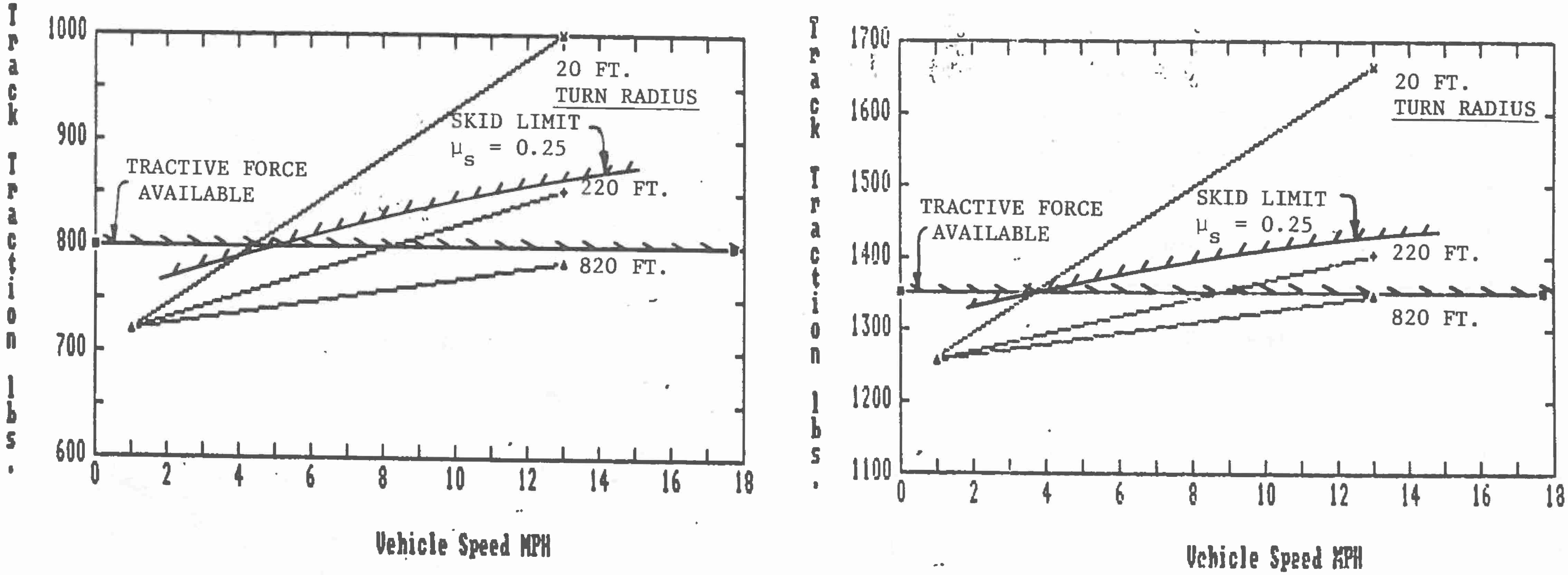
MAX. SPEED = 15 MPH

<u>ON 5% FORWARD GRADE</u>

MAX. SPEED = 7 MPH

Figure 5.2.2-3. Predicted ACCRV Gradability

(ESTIMATED SOIL CBR = 3)

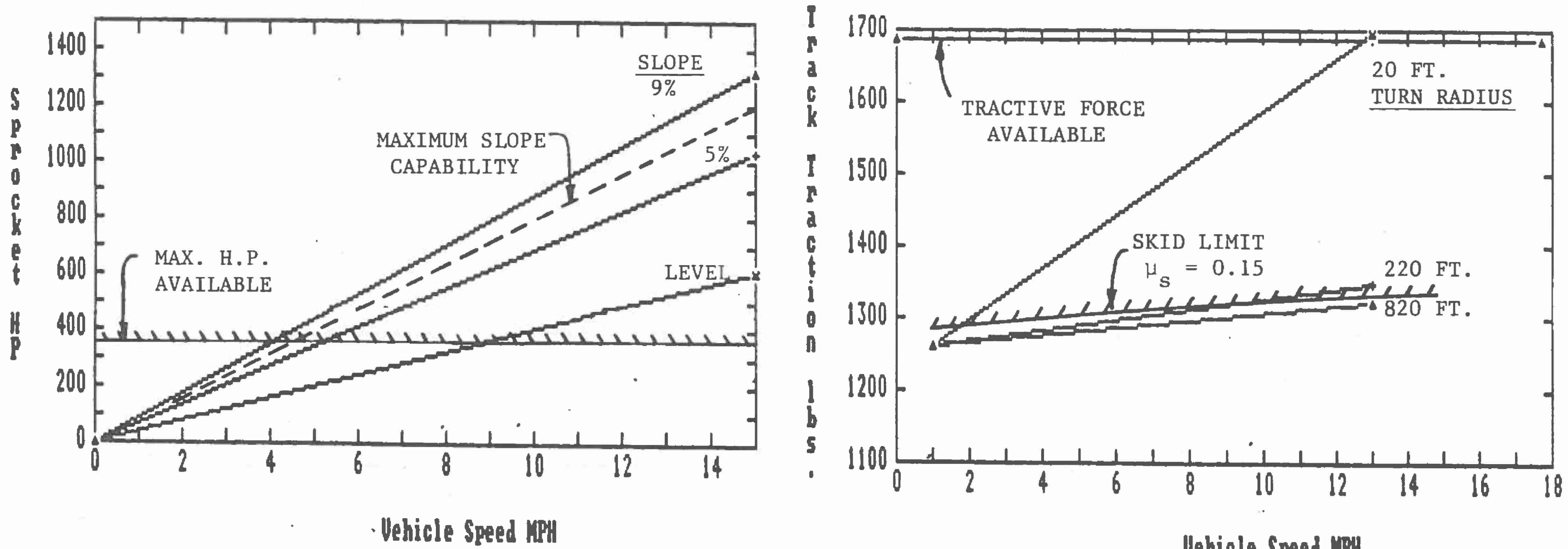


TURNING ANALYSIS - Fine Grain Soil

TURNING ANALYSIS - Coarse Grain Soil

- VEHICLE CAN TURN ON THE LIMITING SOIL CONDITION
- AT SPEEDS IN EXCESS OF 4-5 MPH THE TURN WILL BE LIMITED BY TRACTION RATHER THAN BY SKIDDING

Figure 5.2.2-4. Predicted ACCRV Turn Capability



GRADE ANALYSIS - Snow (with front wheels retracted)

TURNING ANALYSIS - Snow

ON LEVEL GROUND
MAX. SPEED = 9 MPH

ON 5% FORWARD SLOPE
MAX. SPEED = 5 MPH

- VEHICLE CAN TURN ON SNOW
- TURNS ARE RESTRICTED TO LARGE TURN RADII
- FOR SMALL TURN RADII, THE TURN WILL BE LIMITED BY SKIDDING RATHER THAN TRACTION.

Figure 5.2.2-5. Predicted ACCRV Gradability and Turn Capability (Snow)

The vehicle will have a turn capability only at large turn radii. Skidding will limit the turn capability, rather than the available tractive force at the outer track.

5.2.3.1 Performance on Land with Air Cushion Augmentation Versus Wheels

As part of the effort to establish the ACCRV mobility when the vehicle is operated in the hybrid mode, some additional analysis was performed for inclusion in the final report. This additional analysis is intended to illustrate the advantages of the air cushion assisted vehicle when traveling over ground profiles which include various types of craters and other BDR profiles, as compared to operation in a wheeled only vehicle over the same ground profiles.

5.2.3.1.2 Discussion of the Analytical Model for Vehicle Suspension

An analytical model was developed to accurately represent the ACCRV suspension dynamic characteristics for the purpose of predicting the dynamic response of the vehicle. The model is a useful tool for evaluating the sensitivity of the suspension response to variations in suspension parameters.

The ACCRV model is programmed in a modified verison of the Bell generated Vehicle Dynamics (VEHDYN) code. This code can be used to predict: static stability characteristics of a vehicle; dynamic stability characteristics of a vehicle; ride quality; and dynamic loads and clearances. Modeling capabilities feature a wide range of vehicle suspension configurations and key suspension parameters: multiple axles; suspended or rigid axles; individual axle suspension or up to ten articulated suspension units with multiple axles on each unit; rigid or flexible wheels lumped point contact wheel models, or finite element wheel models for the flexible wheel case; unsprung or spring wheel/suspension mass dynamics; and at arbitrary rough ground profiles with large elevation or grade angles.

The time domain computational routine for the analytical model utilizes a numerical integration of the three degree of freedom differential equations of motion to simulate the vehicle dynamic response to a ground input. Longitudinal loads are determined from computed rolling resistance (the rigid body is assumed to have a constant velocity in the direction of motion). Total vertical load and pitching moment terms are determined from the spring/damper models of the wheel and suspension units. A segmented wheel model is used to compute the average tire compression for the finite element wheel mode. Separate equations of motion account for the wheel mass dynamics in the spring wheel mass dynamics mode.

Program inputs include the vehicle rigid body characteristics; wheel/suspension characteristics; articulated suspension unit characteristics, if needed; terrain profiles; and program controls.

Available program outputs include: printed time history data, statistical analysis, and automated time history Versatec plots. The printed time history data consists of the three degree of freedom system parameters outputted at every desired time step. A statistical analysis of user selected variables can be performed. Optional, computer generated, time history plots of key system parameters is available.

A general flow chart of the program is shown in Figure 5.2.3.1.

The cushion was modeled as a set of additional spring/damper systems in parallel with the vehicle suspension elements. Coefficients were introduced into the equations of motion so as to duplicate the predicted air cushion characteristics.

The undeployed paddle track dynamics was simulated using an articulated suspension element with the appropriate dynamic characteristics.

5.2.3.1.3 Ground Profiles

A variety of ground profiles were described in the Statement of Work. These were: surface irregularities up to plus or minus 12 inches; multiple randomly dispersed discrete obstacles, varying in size up to 12 inches; carters wtihout repair of 5 feet in daimeter and 3 feet in depth with a 12 inch tip; and bomb craters with a minimum repair up to 40 feet in diameter (minimum repair of a bomb crater is considered to be a crater which has been backfilled with available material to within plus or minus 12 inches of the original ground surface and has a tip no greater than 12 inches).

The dynamic model test will probably include a requirement to travers rough terrain (potholes, Belgain block, BDR) and bomb craters.

Bell assumed the ground profiles of Figure 5.2.3.2 for use in the dynamic analysis.

5.2.3.1.4 Scope of the Analysis

The dynamic analysis investigated both wheeled and hybrid vehicle response to the assumed ground profiles over a speed range of 10-50 mph. Variations in the suspension stiffness were also considered.

5.2.3.1.5 Results

A complete set of plotted time histories are presented in Appendix 1.

A comparison of the normal acceleration (at the front end of the vehicle) of a wheeled vehicle versus a vehicle in the hybrid mode traversing the specified unrepaired crater is shown in Figure 5.2.3.3. The advantages of deploying the air cushion in order to traverse this particular obstacle is obvious from the curves (reduction in acceleration).

Although the acceleration levels are much reduced with the air cushion, at the higher land speeds, the acceleration of 10g at the drivers seat is significant at the lower land speeds of 10 MPH. To reduce this impact load at the lower speeds, the recommendation would be to add some shock isolation components to the drivers seat to reduce this acceleration. When the vehicle is being operated on wheels, some shock isolation would be desirable anyway.

Future work should include a ride quality assessment due to steady state inputs from Figure 5.2.3.4

The performance summary is given in Figure 5.2.3.5 for waterborne and overland operation, on soft soil, CBR=3.

FLOWCHART

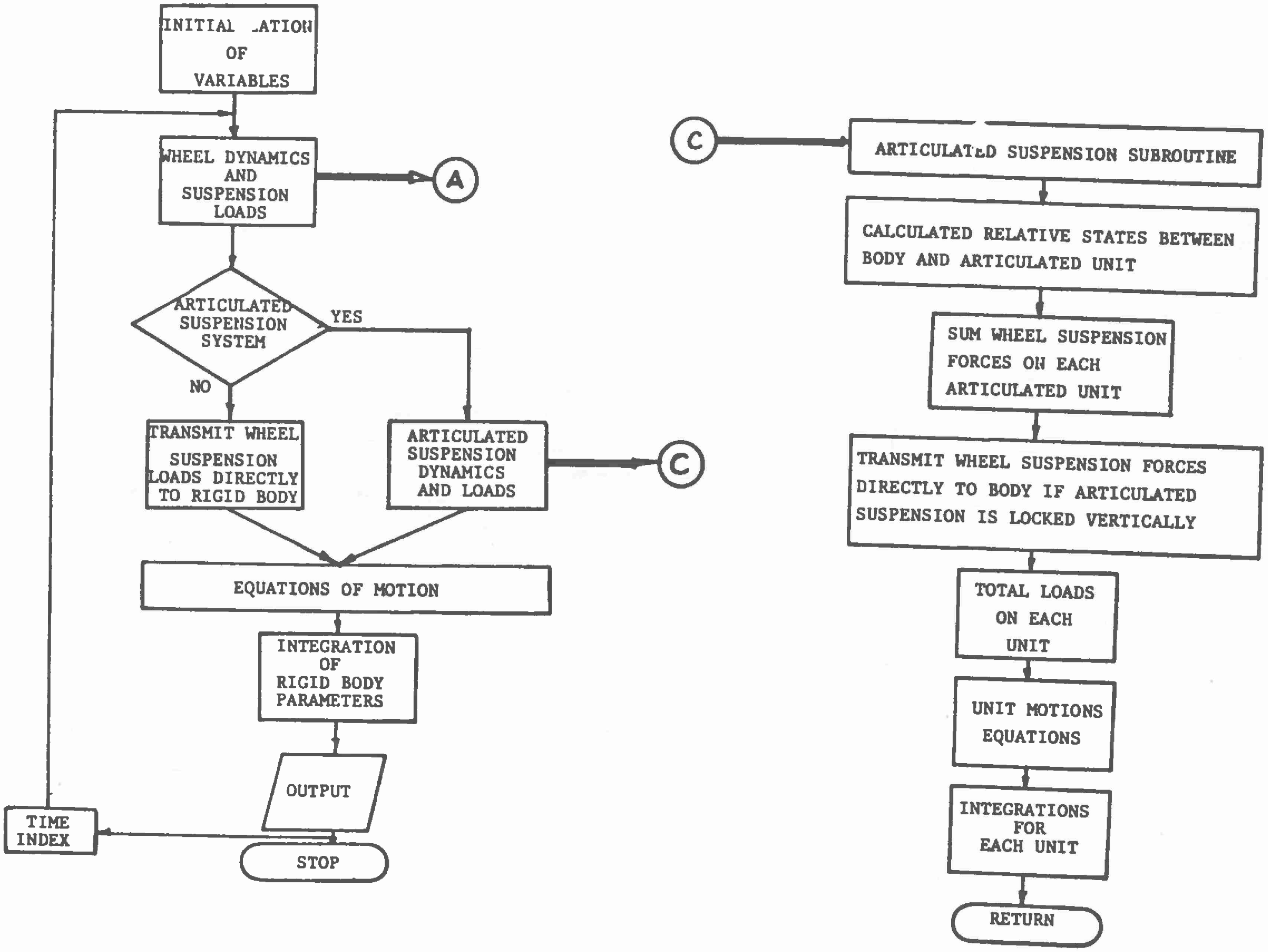


Figure 5.2.3.1 Modified VEHDYN Program Flow Chart

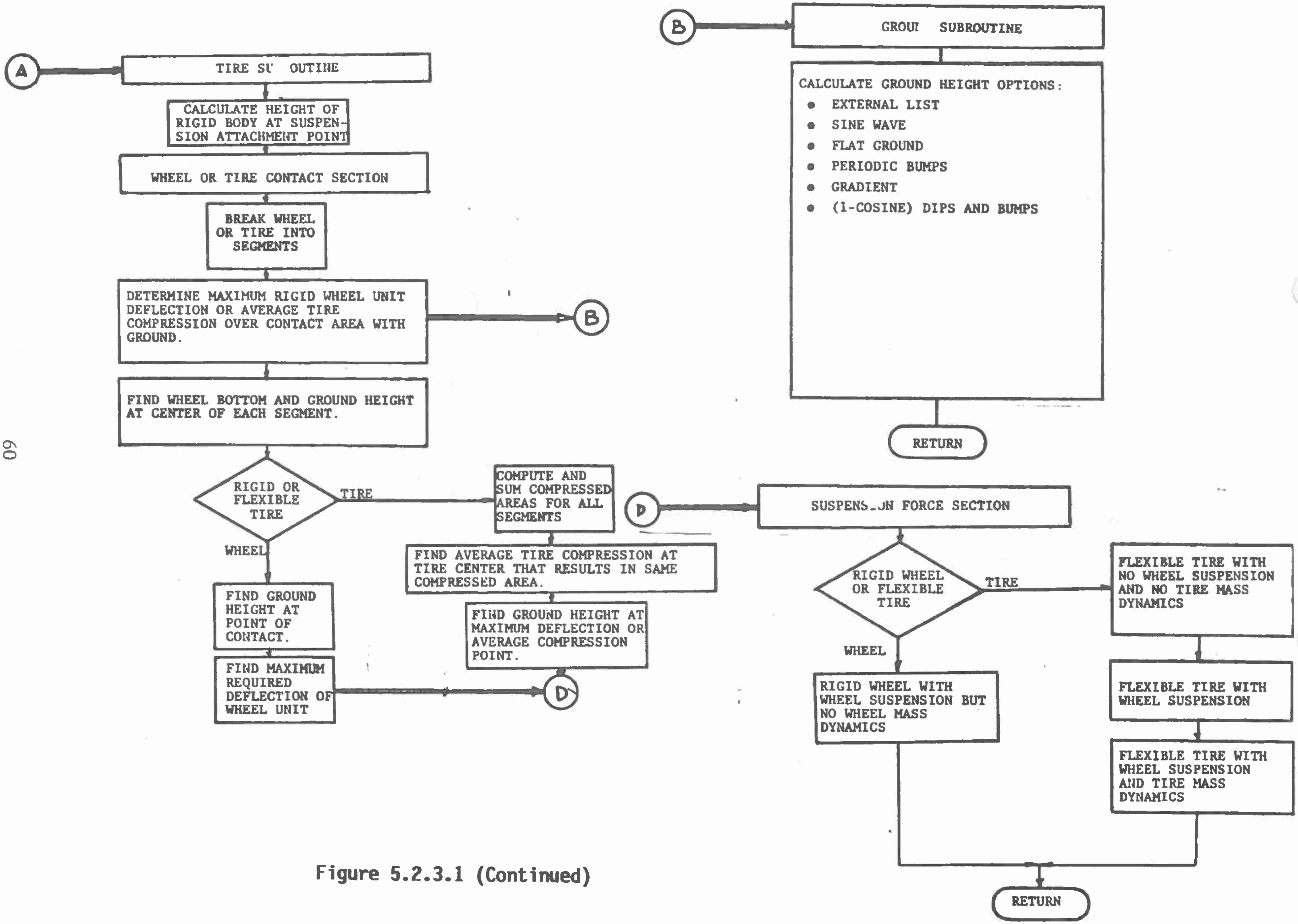


Figure 5.2.3.1 (Continued)

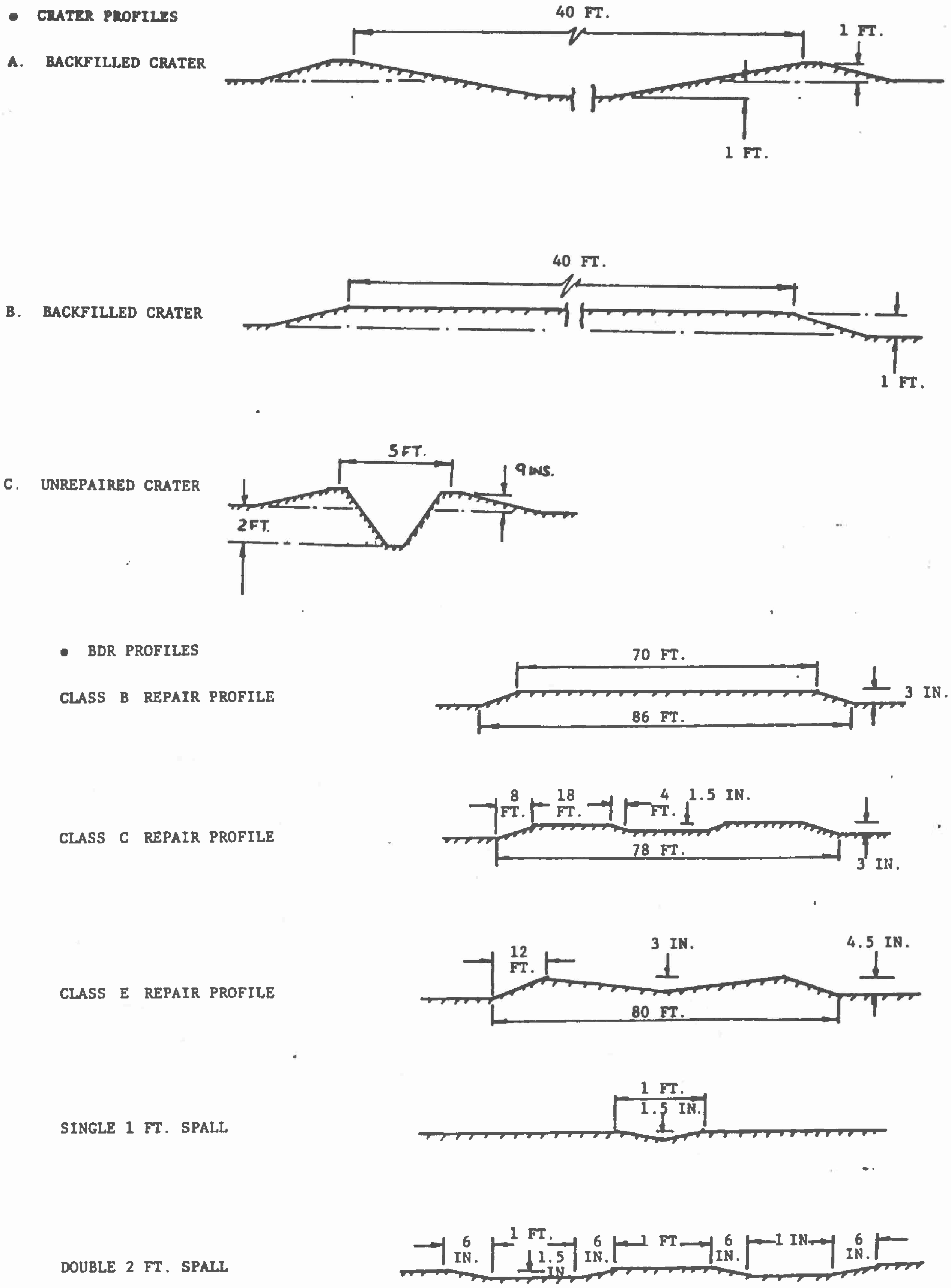


Figure 5.2.3.2 Ground Profiles

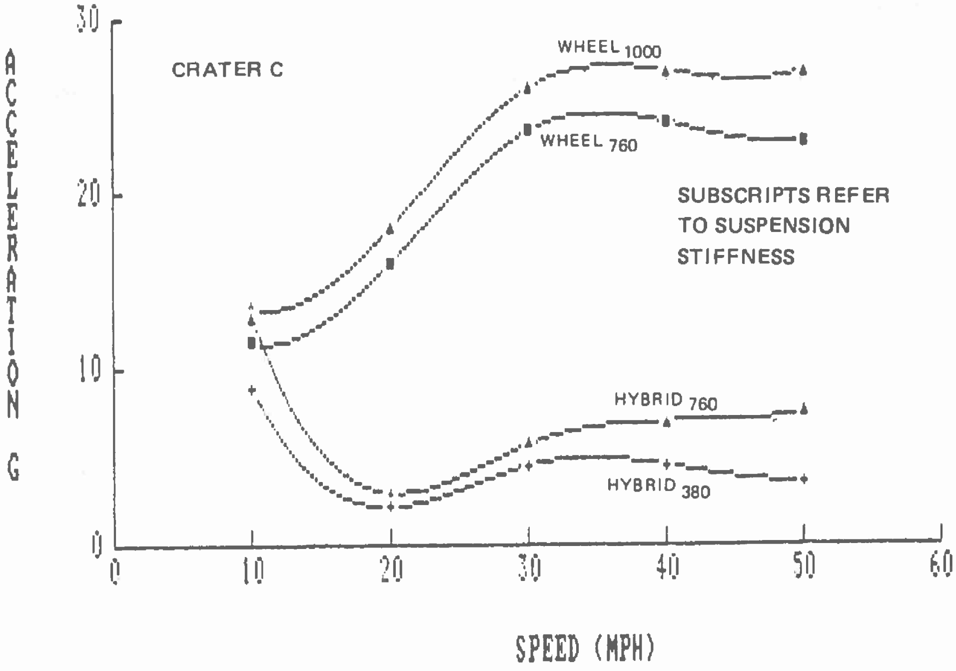
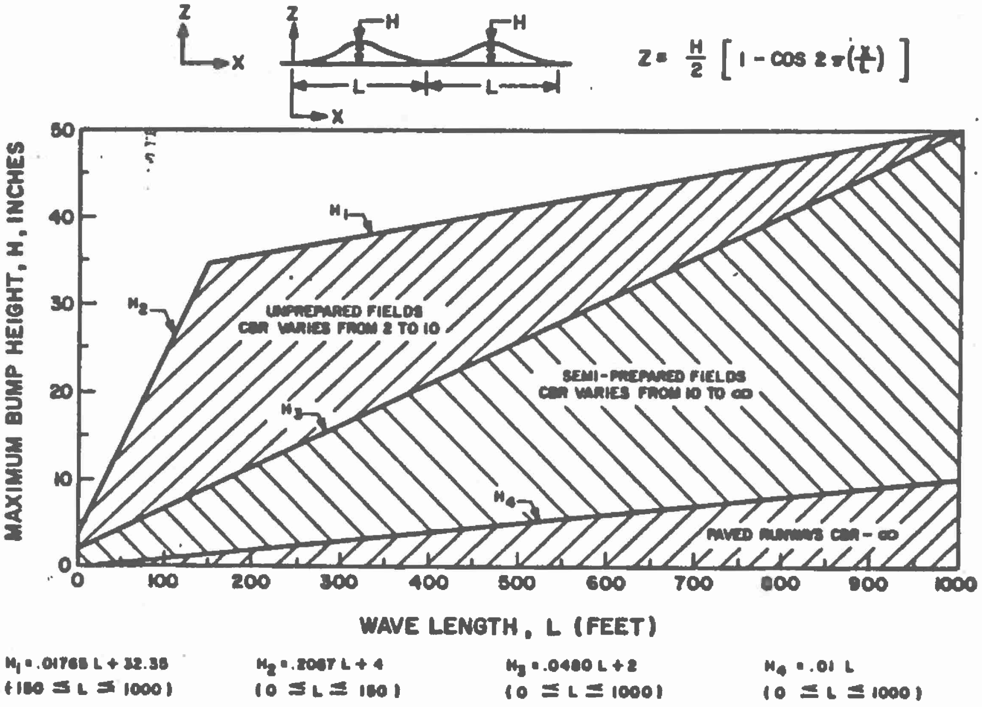


Figure 5.2.3.3 Maximum Forward Acceleration versus Speed



- (1 - COSINE) DIPS AND BUMPS FOR AIRFIELDS AS DEFINED IN MIL-A-8863.

Figure 5.2.3.4 Inputs for Ride Quality

VEHICLE MODE (HYBRID)	TERRAIN/WATER STATE	PREDICTED MAX. SPEED (MPH)	
		LEVEL SURFACE	5% FORWARD GRADE
WATERBORNE	SHALLOW WATER SEA STATE 1	10	N/A
LANDBORNE	MARGINAL TERRAIN (EST. CBR = 3)	15	7
	SNOW (with front wheels retracted)	9	5

Figure 5.2.3.5 Summary

These numbers and figure represent worst case scenarios, on which current CFR vehicles cannot operate. Performance on soil with a CBR greater than 3 is expected to be significantly better, that is, vehicle speed over higher strength surfaces, such as CBR = 10, will be increased proportionately.

6.0 POWER AND TRANSMISSION

6.1 Engine Selection

Power levels shown in Figure 6-1 were computed for achieving the performance levels specified in the statement of work and in NFPA-414 for Class 1 fire fighting equipment. The power levels are for individually driven subsystems and for groups of subsystems driven simultaneously. All power estimates are based on standard day conditions and a vehicle gross weight of 30,000 lb. All drive train losses, momentum drag from the nozzle and operation of auxiliary systems are accounted for in the horsepower requirement listed in the figure for single or combined system operation.

Mode	Condition		Engine, hp
Wheeled	65 mph top speed (incl aero drag)		436
	0-50 mph in 25 sec.		353
	1 mph on 40% grade		35
	50 mph level ground (incl aero drag)		280
Air Cushion	Paddle Track Operation (10 mph)		350
	Lift power		252
Pumping	990 gpm		190
	Momentum drag	708 lb.	
Boom Operation			
Accessories and Losses	Alternator	5	55
	Hydraulic Pump	13	
	Cooling Fan	22	
	Intake/Exhaust	15	

Combined System Operation

1. Pump at 990 gpm while on cushion and station keep with paddle track, operating all accessories. (190 Pump + 252 Fan + 35 stationkeep + 55 accessories) = 532 hp
2. Ascent 40% grade at 1 mph, pumping + all accessories. (35 grade + 190 pump + 3 momentum + 55 accessories) = 273 hp
3. Various Subsystems. As Noted.
4. 10 mph in water on cushion + accessories. (350 track propulsion + 252 fan + 55 accessories) = 657 hp

Figure 6-1. Power Requirements (30,000 lb GVW)

The Detroit Diesel 8V92TA engine was selected as the most suitable power plant to provide the total power for individual and combined operation of the ACCRV systems. Principal characteristics of this engine are given in Figure 6-2.

The engine is a two cycle turbocharged aftercooled diesel using twin blowers. Aftercooling is accomplished with jacket coolant which reduces the change air temperature by approximately 100 degrees F. Total power can be extracted from the flywheel end which incorporates an SAE #1 flange but up to 40% of the power can be tapped from the opposite end of the engine. This is an extremely desirable feature for ACCRV, allowing the fan power to be tapped directly from the engine.

The 8V92TA engine is an improved version of the 8V92 series of engines, which have seen military applications in the U.S. Armys M911 Heavy Equipment Trailer (HET) and the M977 HEMTT. Its use on the P-15 Crash Rescue Truck coupled to an HT750DR transmission verifies that over 95% of parts are in the military inventory and that maintenance manuals are available.

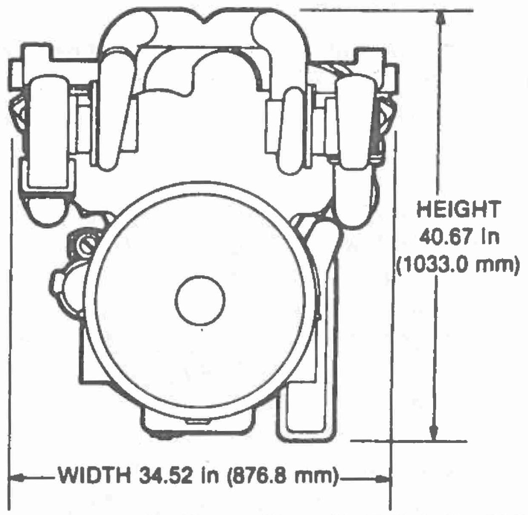
Uprating this engine to achieve a 1 hp/cu. in. was achieved through injector, turbodamper and combustion air flow improvements, coupled with an increase in output speed from 2100 to 2300 rpm. This timely achievement provides an engine with a high hp/weight ratio which is imperative if the C-130 transportability requirement is to be met. The uprated engine has been subjected to 500 hour endurance tests and has passed the 400 hour NATO endurance test. The engine is available for immediate use on prototypes and is a supportable engine suitable for installation on production crash rescue vehicles.

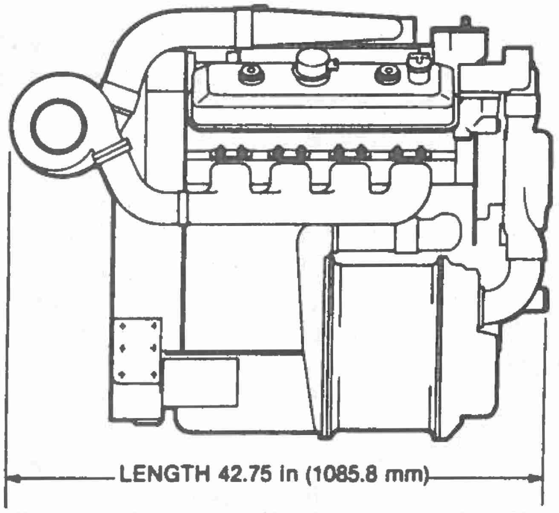
An electronic control system is available for this engine. It is backed by 4.5 million miles of commercial truck testing. Its use provides these significant advantages over a mechanical system:

- Emission Control
- Torque curve shaping to match transmission
- Governor Droop programming
- Minimum SFC operation
- Control of cylinder pressure at high process output
- Automatic protection against
  - Coolant loss
  - Low oil pressure
  - High oil temperature
- Better Starting
  - Reduced crankup time
  - Unaided starting down to 15 degrees F
  - Smokeless in 30 seconds
- Provisions for built-in diagnostics

The electronic control system requires no mechanical linkages between the drivers compartment and the engine.

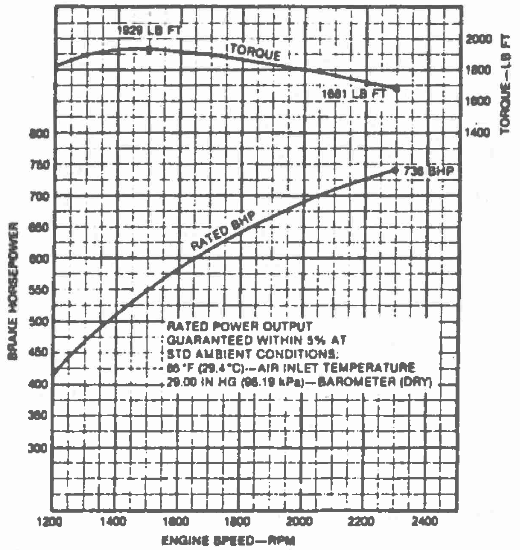
principal dimensions





performance

BASIC ENGINE PERFORMANCE
MODEL 8V-92TA



standard equipment

Aftercooler

Block—Cast Iron

Flywheel

Flywheel Housing

Governor—Limiting Speed

Oil Pan—Capable of 70% grade operation

Starting Equipment—24 volt

Turbocharger—Two turbochargers.
Location determined by installation requirements.

Electronic Control System

specifications

Engine Type	Two Cycle	Torque: 85 °F (29.4 °C)—Air Inlet Temperature and 29.00 in Hg (98.19 kPa) Barometer (Dry)	1929 lb ft (2615 N•m) @ 1500 RPM
Number of Cylinders	8	Compression Ratio	17 to 1
Bore and Stroke	4.84 in x 5 in (123 mm x 127 mm)	Fuel Capability	Diesel #2 through CITE
Displacement	736 cu in (12.1 liters)	Fuel Consumption at Idle	4.4 lbs/h (2.0 kg/h)
Rated Gross Power: 85 °F (29.4 °C)—Air Inlet Temperature and 29.00 in Hg (98.19 kPa) Barometer (Dry)	736 BHP (549 kW) @ 2300 RPM	Weight	2318 lbs. wet

Figure 6-2. Engine Characteristics

At ambient temperatures of +15 °F and 127 °F the 8V92TA engine can be started in less than 30 seconds. At temperatures of -25 °F and +15 °F DDA has traditionally met military requirements for unaided starts in one minute provided the engine is prepared for cold weather operations with suitable grades of fuel and oil. At temperatures below -25 degrees F, starting aids are required.

Detroit Diesel does not recommend any warm-up procedure. However, in cold weather, after the engine is started, it should be run above idle to ensure that all systems are operating properly. Once this is done full operation of the engine can proceed. The electronic control system in addition to aiding rapid start ups, reduces detonation characterizing a cold diesel and nearly eliminates smoke during warmup - these features enhance the ability of ACCRV to respond quickly to emergency situations.

6.2 Transmission

The HT-750DR-5 speed automatic transmission was selected and coupled to the DD8V92TA engine to meet the acceleration, gradability and top speed requirements of the ACCRV. Principal characteristics of the HT750DR transmission are given in Figure 6-3 specifications.

The HT750DR is an automatic transmission rated at 445 hp and 1300 ft-lb torque @ 2400 rpm. For crash truck applications, intermittent operation at 545 hp and a max torque of 1575 ft-lbs is permitted and will be approved by Detroit Diesel Allison*. Several torque converters are available. The TC 499 with a stall torque ratio of 2.09 has been selected for a best match with the 8V92TA engine output torque. An automatic lockup clutch effective in all forward ranges provides maximum performance and fuel economy. Five ranges in forward provide ratios varying from 7.973 to 1.000 and one gear in reverse. Provisions exist in the transmission to inhibit automatic upshift or down shift when operation over water in paddle track mode or cushion borne operation is desired. Second gear start is recommended for ACCRV under all normal operating conditions, with first gear used only for extreme slope climbing and/or extremely low speed operation.

Salient features of this transmission include:

- Automatic upshifting and downshifting on the upper four drive ranges, with lockup provisions in each range.
- Second gear start standard.
- Multidisc self adjusting hydraulic clutches.
- Inhibitors to prevent harmful downshifts or reverse shifts.

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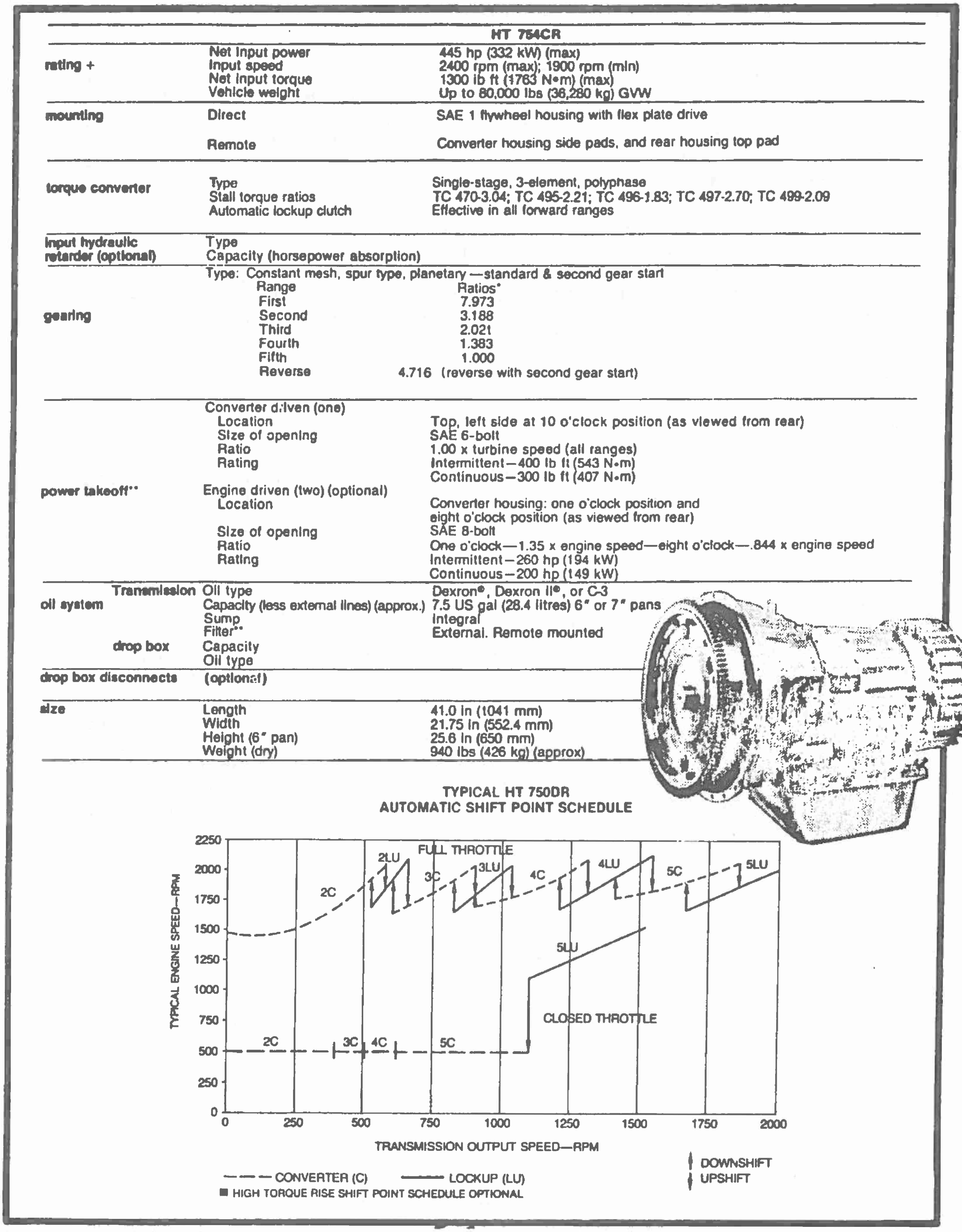
*Personal communication with D. Herling and E. Adams, Project Engineer DDAD transmissions 11-7-85.



			HT 754CR
rating +		Net input power	445 hp (332 kW) (max)
		Input speed	2400 rpm (max); 1900 rpm (min)
		Net input torque	1300 lb ft (1763 N•m) (max)
		Vehicle weight	Up to 80,000 lbs (36,280 kg) GVW
mounting		Direct	SAE 1 flywheel housing with flex plate drive
		Remote	Converter housing side pads, and rear housing top pad
torque converter		Type	Single-stage, 3-element, polyphase
		Stall torque ratios	TC 470-3.04; TC 495-2.21; TC 496-1.83; TC 497-2.70; TC 499-2.09
		Automatic lockup clutch	Effective in all forward ranges
input hydraulic retarder (optional)		Type	
		Capacity (horsepower absorption)	
gearing		Type: Constant mesh, spur type, planetary —standard & second gear start	
		Range	Ratios*
		First	7.973
		Second	3.188
		Third	2.021
		Fourth	1.383
		Fifth	1.000
		Reverse	4.716 (reverse with second gear start)
power takeoff**		Converter driven (one)	
		Location	Top, left side at 10 o'clock position (as viewed from rear)
		Size of opening	SAE 6-bolt
		Ratio	1.00 x turbine speed (all ranges)
		Rating	Intermittent—400 lb ft (543 N•m) Continuous—300 lb ft (407 N•m)
		Engine driven (two) (optional)	
		Location	Converter housing: one o'clock position and eight o'clock position (as viewed from rear)
		Size of opening	SAE 8-bolt
		Ratio	One o'clock—1.35 x engine speed—eight o'clock—.844 x engine speed
		Rating	Intermittent—260 hp (194 kW) Continuous—200 hp (149 kW)
oil system	Transmission	Oil type	Dexron®, Dexron II®, or C-3
		Capacity (less external lines) (approx.)	7.5 US gal (28.4 litres) 6" or 7" pans
		Sump	Integral
		Filter**	External. Remote mounted
	drop box	Capacity	
		Oil type	
drop box disconnects		(optional)	
size		Length	41.0 in (1041 mm)
		Width	21.75 in (552.4 mm)
		Height (6" pan)	25.6 in (650 mm)
		Weight (dry)	940 lbs (426 kg) (approx)

TYPICAL HT 750DR
AUTOMATIC SHIFT POINT SCHEDULE

Figure 6-3. HT754CR Transmission Specifications

- Mechanical shift modulation
- Adapter for drop box installation

The HT750DR transmission is currently in the Military inventory. Among other applications, it is used on the P-15 Crash/Rescue truck, coupled to the 8V92T engine in a twin engine/transmission installation. All parts are in the military inventory; parts lists and maintenance manuals are currently available.

6.3 Power Distribution

The requirement for a single diesel engine to supply all the power on the air cushion crash rescue vehicle demands a power distribution system capable of simultaneously accommodating all subsystem demands for varying power levels and speeds, while at the same time limiting power to some components under various operating conditions. To achieve this with minimum complexity and weight the power distribution system shown in Figure 6-4 was selected. Power train components used in the power distribution system are listed in Table 6-1.

Perhaps the best way to describe the functional characteristics of this system is by addressing its operation in the various operating modes.

6.3.1 Mode 1 - Drive Mode - This mode is used on paved, gravel or dirt roads suitable for normal vehicular traffic, or when operating off road on suitably supportive surfaces. The vehicle is operated in the same manner as a nonaugmented crash fire rescue vehicle, and power distribution is accomplished in the conventional manner.

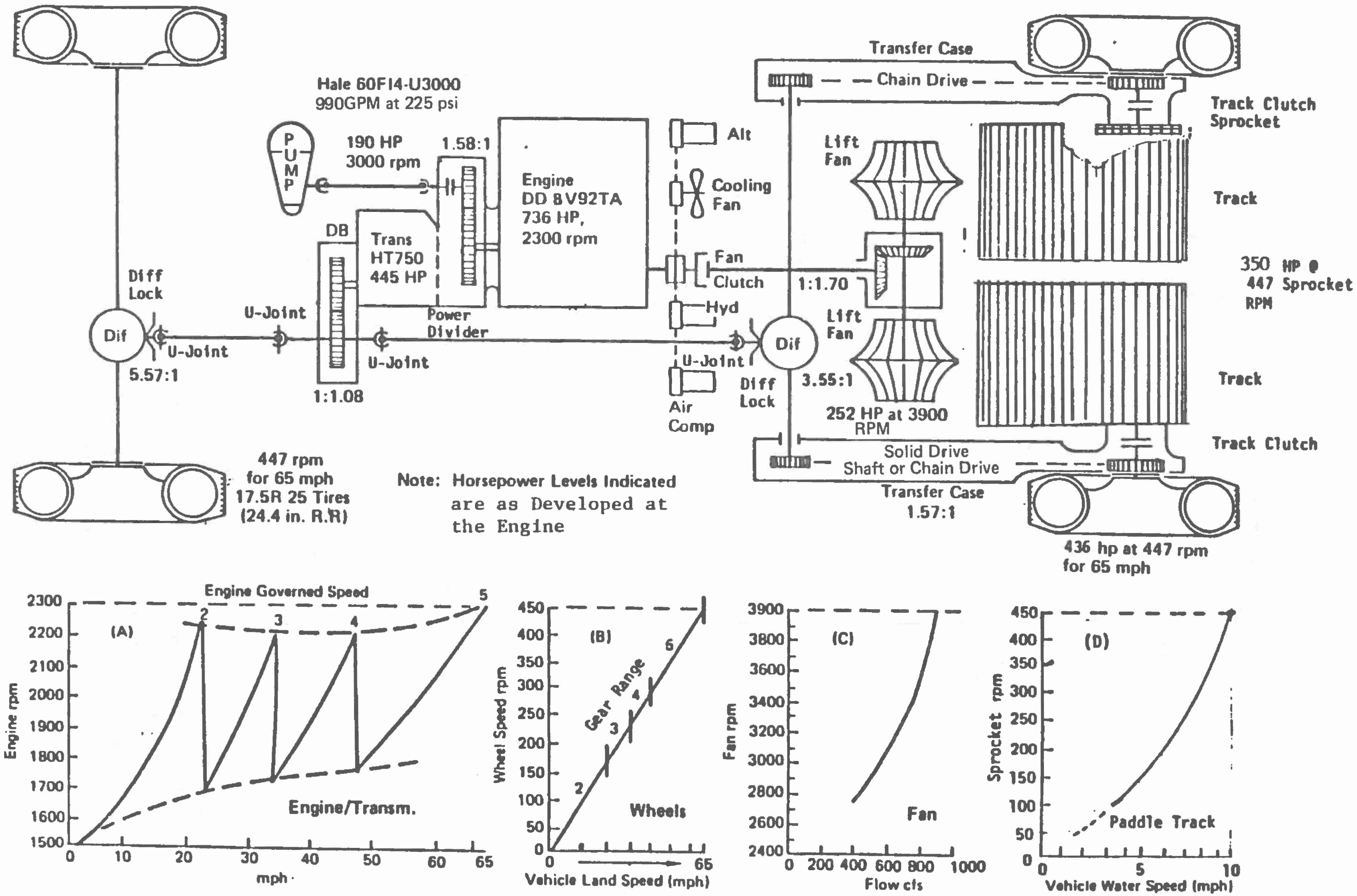
Power from the engine is transmitted through the power divider to the Allison HT750DR. The HT750DR in turn provides power to the drop box which directs power to the front and rear axles. All ranges of the HT750DR are usable with engine and transmission output speeds related as shown in Figure 6-4 adjusted for 2300 input rpm. Under this condition, however, the electronic control system governor on the engine limits the engine power curve so that at no time does the maximum engine net torque exceed the allowable 1300 ft-lb, or intermittent 500 hp that can be sustained by the transmission and power divider. Analysis indicates that all mobility requirements in the wheel drive only mode can be met or exceeded with only 436 hp delivered to the transmission, which is considerably less than the power available under the limiting action of the electronic governor. See Figure 6-5.

The power train after the HT750DR is conventional in concept although of a customized configuration. The output from the transmission passes through a drop box which is rigidly attached to the transmission housing. The function of the drop box is threefold:

1. It provides the required 23.3 inches offset between the transmission output shaft and drive shaft.

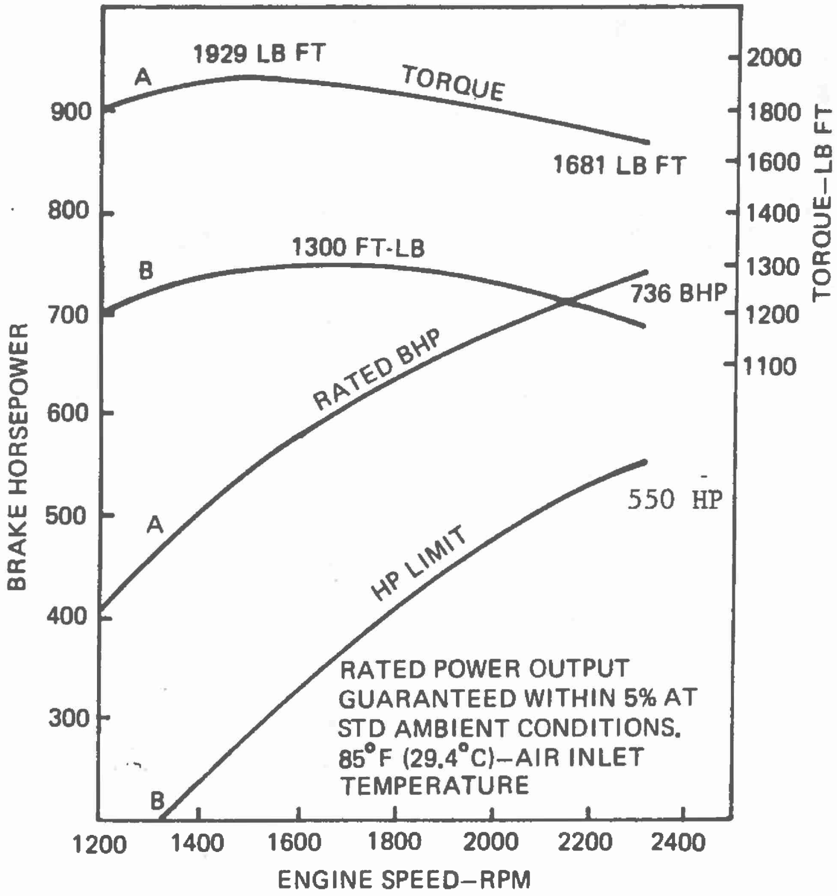
TABLE 6-1. POWER TRAIN COMPONENTS

Engine	- DD8V92TA	- 8 cylinder, 736 hp turbocharged 2 cycle watercooled diesel 43L x 35W x 41H, 2090 lbs. dry
Power Divider	- Walter	- Multi-disc oil cooled clutch with modulator to engage the main power transmission. Internally clutched pump drive 1.58:1 step-up ratio.
Transmission	- DDA HT750DR with TC 499 Torque Converter	- Fully automatic with manual override to inhibit upshift 1st - 7.97:1 4th - 1.40:1 2nd - 3.19:1 5th - 1.00:1 3rd - 2.07:1 Rev - 4.47:1
Drop Box	- SPECO Div. Kelsey Hays (new design)	- Two mesh - 23.3 in. offset 1.08:1 step-up ratio
Universal Joints	- DANA or Equiv. (Std)	- Commercial truck U-joints
Shafts	- DANA or Equiv. (Std)	- Commercial truck 4-1/2" dia. shafts
Front Axle	- Rockwell FDS 1600	- Single reduction hypoid gear with driver selected with differential lock 5.57:1 reduction; integral king pin and power assist arm brakes and drums.
Rear Axle	- Eaton 16121 Series	- Single speed bevel gear with driver selected lockup differential 3.35:1 reduction.
Transfer Case	- Chain Drive (new design)	- 8-140 hi-strength roller chain 52,000 lb. tensile - 1.57:1 sprocket reduction ratio aluminum housing.
Fan Clutch	- Morse Type MG 400	- Overrunning (CAM) clutch in series with hydraulically actuated engage/disengage disc clutch.
Fan Shaft		- 4.0 in. OD x 1/8 wall shaft tubing.
Fan Gearbox	- SPECO Div. of Kelsey-Hays (new design)	- Single Mesh Bevel Gear 1.70:1 step-up ratio aluminum housing.



Note: Horsepower Levels Indicated are as Developed at the Engine

Figure 6-4. Power Distribution System



Curves A used only when left fans are operating.
Curves B used in all modes except when left fans are operating.

Figure 6-5. Performance of Model 8V92TA Engine Basic and with Torque Limiter

2. Splits the power output to the forward and rear differentials.

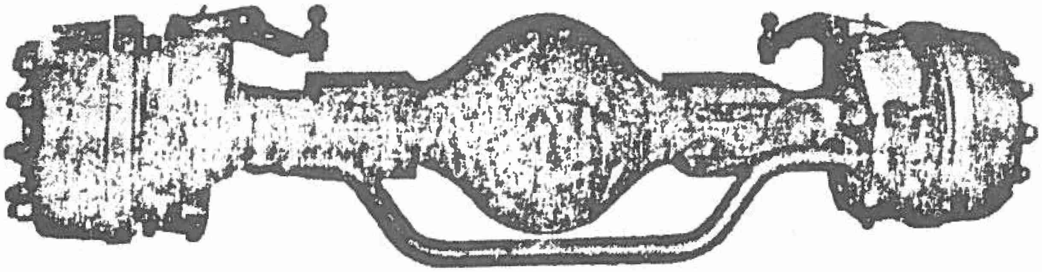
3. It adjusts the transmission output rpm to achieve 65 mph top speed with the tires inflated to 40 psi (24.4 in. rolling radius).

The drop box increases the output shaft speed by a ratio of 1.08:1.

Drive Shaft and Universal Joints - A floating shaft with universal joints at either end is used to transmit torque to the front axle. The shaft is installed at a nominal angle of 7 degrees between flanges. When the total vehicle weight is supported on the wheels, the shaft can transmit full power. In the hybrid mode when the front wheels are lowered to come in contact with the ground, the shaft angle increases to 11 degrees but the torque transmitted at this steeper angle is limited by traction to only 30% of full output.

The shaft extending aft to the rear axle is also coupled with universal joints at either end. Unlike the forward shaft, however, neither end is required to accommodate angular deflections as both the drop box and the rear axle are mounted to the chassis. The bias angle on the rear shaft will be 5 degrees or less.

Differentials - The forward differential provides a 5.57:1 ratio in a single reduction hypoid gear, housed in an aluminum case. The differential incorporates a lock mechanism, a feature which is driver activated for positive wheel drive. The forged case, Figure 6-6, has provisions for mounting suspension brackets, yokes, brakes and drums. In addition, the front axle includes the king pins and steering arms for attaching steering drag links.



- **MAXIMUM ADAPTABILITY TO MOST VEHICLE DESIGN**
- **35° or 28° MAXIMUM TURNING ANGLE**
- **STOPMASTER BRAKES — AIR OR HYDRAULIC**
- **DISC OR CAST SPOKE WHEELS**
- **LARGE RATIO SELECTION**
- **RH OR LH SINGLE REDUCTION OR DOUBLE REDUCTION CARRIER**
- **HYPOID GEARING**
- **5° 30′ KING PIN INCLINATION**
- **BUILT-IN 2° CASTER AND 1/4° CAMBER**
- **COMPATIBLE WITH SSHD REAR TANDEM DRIVES**
- **OPTIONAL HYD. CYL. POWER ASSIST ARM ON KNUCKLE**

Figure 6-6. FDS 1600 Front Driving Axle

The rear axle is modified to accept a chain drive transfer case which comprises the trailing link that supports the rear wheels and track system. A heavy series Morse 8-140-H chain (1 in. wide, 1-1/2 in. pitch, 52,000 lb. tensile) is used to transmit power from the axle to the rear wheels. A telescoping drive shaft is an attractive alternative that could be used in place of a chain drive. If the paddle tracks were relocated, a different rear end arrangment could be used, at which point it would be appropriate and necessary to consider different rear end configurations. Again, this is a task to be investigated in Full Scale Development.

The rear differential uses a 3.55 reduction. This ratio is combined with the 1.57 reduction of the chaindrive to match the 5.57 single reduction rates of the forward axle differential. The 3.55 ratio is the lowest commercially available ratio for this series of axles. The 1.57 chain drive ratio is needed in order to facilitate physical attachment of the chain sprocket to the rear wheels/tracks at a suitable diameter.

6.3.2 Mode 2 - Pump and Drive Operation - This mode is used when it is necessary to use the fire fighting system and at the same time maneuver the vehicle around the fire. This is accomplished through the use of a power divider, which contains the following active element:

1. An oil cooled multiplate power transmission clutch mounted to the engine flywheel. It transmits power to the HT750DR transmission torque converter when engaged.
2. A water pump engage/disengage clutch which transmits power from the engine flywheel directly to the water pump when engaged.
3. A control system to:
   - engage/disengage the pump clutch
   - modulate the engagement of the main power transmission clutch.

For pump and drive operations, the power transmission clutch is disengaged, the pump clutch engaged, and the engine brought up to the speed necessary for fire pump operation, approximately 1900 rpm. Movement of the vehicle is accomplished by selecting a desired drive range on the HT750, usually 1st, 2nd, or reverse, and then progressively engaging the power transmission clutch until the desired speed or distance is reached. Modulation of the power transmission clutch is placed under the control of the driver's accelerator pedal. Power out of the HT750 is directed to the wheels as in Mode 1.

6.3.3 Mode 3 - Augmented Drive Operation - The purpose of this mode is to get the vehicle to the desired destination over surfaces which cannot be traversed by wheeled vehicles, such as soft soil, mud, fluid soil and water. This is accomplished by using air cushion support augmentation and either of two propulsion methods.

The first propulsion method is used when capability to traverse marginal terrain (marsh, snow, crudely filled bomb craters, or soft soil) is required. The air cushion is deployed, the fans are engaged and all wheels are lowered to the ground. The maximum weight carried by the suspension is approximately 30% of the gross vehicle weight, sufficient ground pressure is thus availed to utilize the tractive capabilities of the surface without sinking in and becoming immobilized. If this percentage is increased, the vehicle has a tendency to sink further in the marginal terrain and bog down. Decreasing the weight on the suspension may result in loss of slope climbing ability. Power for locomotion is provided through the drive train as in Mode-1.

The second propulsion method, used mostly on water but can also be used when the wheels are unable to propel the vehicle in the cushion augmented mode. It is similar to the first except motion is accomplished through the use of paddle tracks, driven by the rear wheels. The front axle can be retracted making little or no contact with the surface, to reduce resistance to motion or can remain down to assist steering and propulsion on water. On water, all vehicle weight is supported by the cushion except for 700 lb. flotation provided by the partially immersed rear wheels. On fluid soil or mud, the track will assume sufficient weight to produce the required draw bar pull.

Each of the two paddle tracks installed between the rear wheels of the vehicle is rigidly bolted to the axle of the rear wheel. It rotates with the rear wheel and is driven by the chain drive telescoping drive shaft through the rear differential. Most suitable operation in the water is achieved with the transmission in the fifth gear range, which gives a sprocket speed of up to 450 rpm (insets A and D of Figure 6-4). Since track is driven through the transmission and rear axle differential, complete flexibility exists for forward speed control, reverse, and steering.

The fans used to supply air to the augmenting cushion require additional horsepower over that used in Modes 1 and 2. Therefore, for cushion augmented operation of the vehicle, the electronic engine control unit is returned to the higher power curve A in Figure 6-5, after engagement of the cushion fans. Since the fan draws 252 HP, there is no fear of overloading the transmission at full engine power output.

Lift power is provided by engaging the hydraulically actuated fan clutch coupled to the forward end of the engine crankshaft. This is a centrifugal overriding clutch which drives the lift fans through a step-up angle gearbox. Its ability to freewheel in the reverse direction prevents the lift fans from back driving the engine during the transmission shift sequence. The maximum power tapped from this end of the engine is 252 hp. It is limited by the maximum fan speed of 3900 rpm, which corresponds to the governed engine speed of 2300 rpm.

Engagement of the cushion fans causes two additional events to occur: 1) the power transmission clutch in the power divider is disengaged, and 2) the engine governed speed is automatically set to 2300 rpm. Conditions are now set for making the transition from wheel supporting surfaces to those requiring augmentation. The fans, being at max rpm, provide the greatest lift clearance, and the power divider can be modulated to provide forward or reverse motion through the wheels or tracks depending on terrain characteristics.

After transition, forward motion is best achieved by selecting the transmission range desired, and fully engaging the power divider's main power transmission clutch; maximum acceleration and top speed will be achieved as the transmission automatically progresses through the gears. Under these conditions, the lift fans do not operate at constant speed. Being directly coupled to the engine, their speed will vary between 3900 and 2700 rpm as engine variations in speed are demanded by the transmission gear setting and automatic shift point controls. Nevertheless, suitable air cushion gaps will be maintained.

Vehicle speed control is accomplished as in Mode 2. Releasing the accelerator pedal disengages the power divider power transmission clutch; applying the brakes slows or stops the tracks. Limited forward speeds can be achieved by using lower transmission gear ranges and for power divider clutch modulation.

Overwater steering is achieved by braking one track. This is implemented through the steering wheel with a linkage whose braking force is proportional to steering wheel displacement. The sense is same as for steering the vehicle on land. Turning the wheel to the right applies the brake to the right track causing the vehicle to turn to the right. This is readily implemented with a dual zone diagonal (front left/rear right) braking system. The front wheels are totally inactive in the track mode of operation, if the front wheels are not retracted, although they may assist steering and propulsion on water. Note that if the paddle tracks are relocated and hydrostatic drive utilized, differential power (one track operating in the forward direction, the other track reversed) can be used for more efficient turning.

6.3.4 Pump and Drive in the Augmented Mode - This mode is identical to the augmented drive mode except that the water pump clutch is now engaged. Engaging the water pump clutch has only one effect on the power distribution system and that is to turn the engine speed control over to the water pump pressure governor, which varies engine speed to maintain 225 psi in the fire fighting system. Engine speed will vary between 1750 and 1900 rpm as the demand for water discharge goes from 0 to 845 gpm. This corresponds to a fan rpm of 2970 to 3200 rpm.

The fan rpm and flow corresponding to this range of engine speeds is shown in inset (C) of Figure 6-4. Here it is seen that the flow varies between 500 and 700 cfs which simply varies the gap of the cushion. The resulting gap clearance is quite adequate for station-keeping/creep operation.

Sufficient flow is always available and the fraction of vehicle weight carried by the cushion does not change since fan pressure over this entire range of flows remains essentially constant. Best cushion performance will be obtained at high rpm/high flow. Thus, the operator will open the throttle to increase fan speed to suit desired conditions. Speed control and steering functions are identical to Mode 3.

6.3.5 Auxiliary Systems Drives - The fire system water pump is engine driven. The power divider installed between the engine and the transmission provides a convenient power take-off point, while it simultaneously steps up the engine rpm to the level required to develop full pump output. A short shaft couples the pump to the power divider. The power divider uses two sets of spurgears, coupled through a hydraulic clutch, with an output/input ratio of 1.58. For efficient pump operation, it is necessary to run the engine at 1750 to 1900 rpm.

The Detroit Diesel 8V92TA rear housing is equipped with power take-off pads for accessory drive; the selection of a suitable turbocharger arrangement allows most of the pads to be accessed. The following accessories will be direct driven and mounted to the rear housing:

- Steering/lift, and boom hydraulic pump
- Power divider hydraulic control pump
- Air compressor
- Alternator

7.0 SUSPENSION AND FLOTATION

7.1 Introduction

The all-terrain and all-weather operation requirement coupled with the weight and space restrictions for transportability in a C-130 impose rather stringent requirements on the land suspension and water flotation systems.

For land operation on firm surfaces, the ACCRV must be able to operate on runways and highways at high speed with the air cushion components retracted and stowed. Operation off road and on snow or ice is also required. A conventional 4-wheel drive springing and damped system, with a differential lock feature will be used to provide good traction over a broad range of weather affected terrain conditions. For operation in swamps and on open water the cushion will be deployed. This introduces a need for adjustable wheel/track distance from the hull bottom. The variable height suspension system permits lowering of the rear wheel/track sprocket centerline to provide waterborne propulsion, and easy transition from water to land.

For land operation on soft surfaces and also to provide improved obstacle negotiation crossing craters, ditches or other rough terrain features that can not be achieved with the wheel/spring/damper system alone, the cushion will be deployed and the wheels and track will be used for traction. This requires that the wheel suspension provide a controlled load and vertical displacement of the wheels. The normal position will now be six inches below the fully wheelborne case with the suspension springs fully extended.

Over-water operation requires the inherent capability of the craft to float safely in the event of engine or other major system malfunction. Also, hullborne operation is required during the rescue portion of the mission. Firefighting can be accomplished while either on-cushion or hullborne but the on-cushion waterborne stability is too low to permit boom rotation through 360 degrees (except with optional buoyancy bags). The suspension and flotation system concepts and trades to provide this mission flexibility are discussed in this section.

7.2 Front Suspension

A conventional truck type single beam front axle with coil springs and hydropneumatic dampers was selected as the baseline suspension system. Other concepts evaluated included leaf springs and independent front wheel suspension designs. While improvement in ride quality would result from independent front wheel suspension, the weights increase by at least 25% and cost increase by a similar amount discouraged its use. Since the air cushion system can be used to reduce off-road wheel loads, the use of independent front wheel suspension was eliminated from further consideration.

The ACCRV suspension was designed to permit 100% of the load to be supported on either pair of diagonally opposite wheels and for traversing obstacles up to 12 inches in height. This, plus the need for vertical adjustment to adapt the system to waterborne or landborne operation led to utilizing the same type of trailing arm, concentric coil spring/hydropneumatic strut system used on the rear suspension. Figure 7-1 illustrates the selected concept. The total wheel travel required is less at the front than the rear units since the front wheels can be retracted in waterborne and marginal soil operation if necessary. The trailing arms are attached to pivots forward of the wheels and through a soft pad to the spring cups on top of the axle. The coil spring/strut units are mounted to structure above and to the same axle pads but without the stroke amplification needed at the rear wheels. The combined set of trailing arm suspension and axle systems will accommodate the range of land and waterborne positions required.

Figure 7-2 illustrates the hydropneumatic shock strut; it will be the same for both front and rear suspensions.

In use, the oleo element retracts the wheel compressing the spring for waterborne operation and provides damping for wheelborne or hybrid operation. The pneumatic element maintains the wheel load in hybrid operation. The spring functions for wheelborne operation only. Specially designed struts are required for this application, but they do not involve any new technology.

The front axle includes provisions for hydraulic power steering assist. Steering mechanisms and brake systems are also integral with the selected axle providing proper toe-in and camber for turning operations. The axle selection and description is included in Section 6, Power Distribution. The wheels and tires selected are the same as those used on the P-19 vehicle. The wheel has an unrestrained diameter of 52.8 inches, and a width of 17.5 inches across the tire. Various tread designs are available for improved traction in off-the-road operation.

7.3 Rear Suspension

The rear suspension system configuration is similar to the forward system except that the wheels are mounted on longer trailing arms. A similar coaxial coil spring/damper unit is used for prepositioning and load control. The trailing arms for the rear suspension have a dual function. The first is to provide independent wheel suspension for the rear wheels. The second is to serve as a transfer case housing for the chain drive to the rear wheels and tracks. These transfer case trailing arms transfer the wheel loads to the structure through the spring/damper unit similar to the front; but whereas the forward suspension uses thick elastomeric pads between the axle and the spring/damper to compensate for the axle cant angle, the rear system operates independently. A sway strut takes out the side load. The system is illustrated in Figure 7-3.

The spring/damper system shown in Figure 7-2 provides the initial adjustment of vertical wheel position by changing the pressure balance between the gas and liquid sides of the piston. The strut will adjust the transfer case to a new static position. In the dynamic mode the

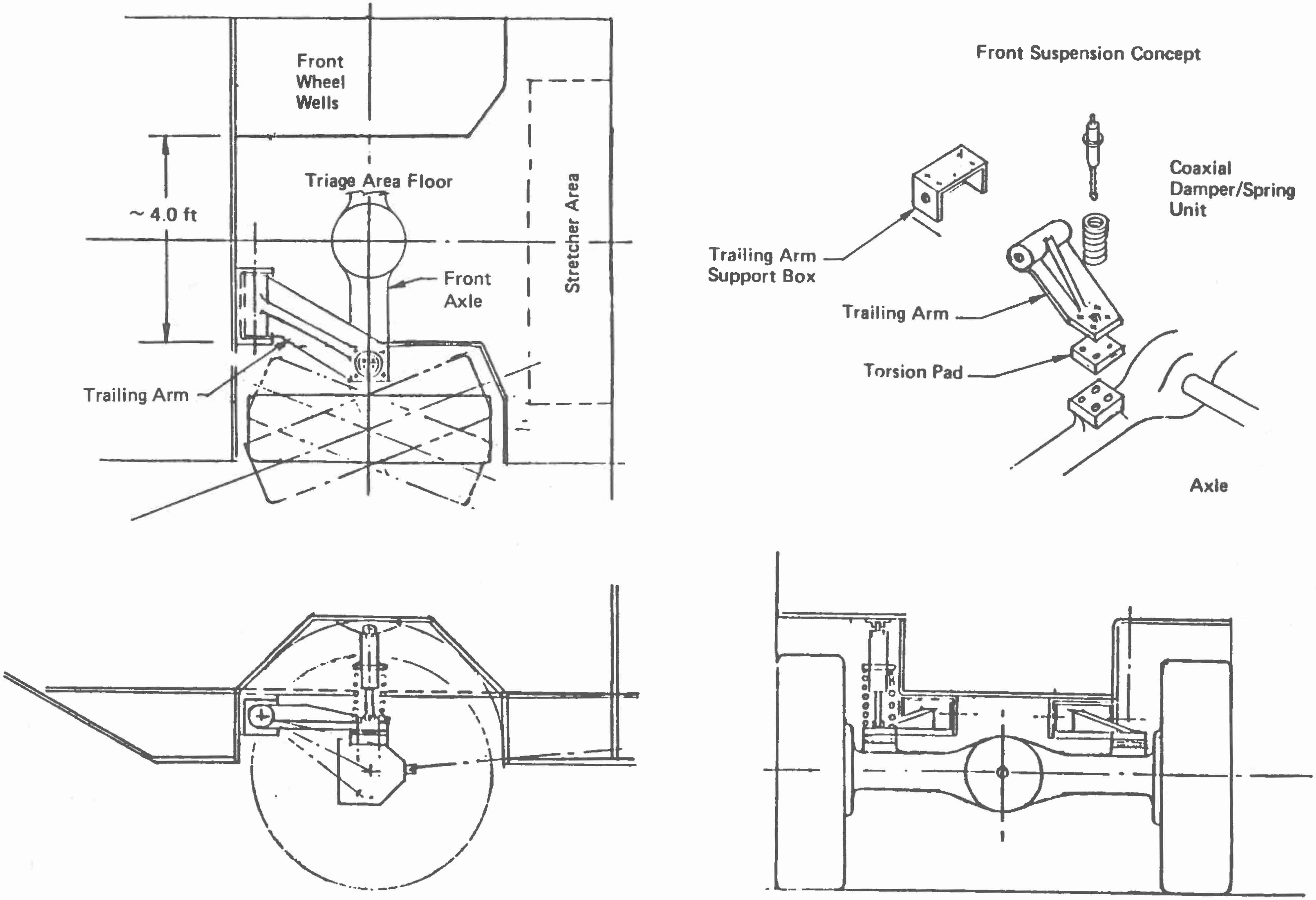


Figure 7-1. Front Suspension Concept

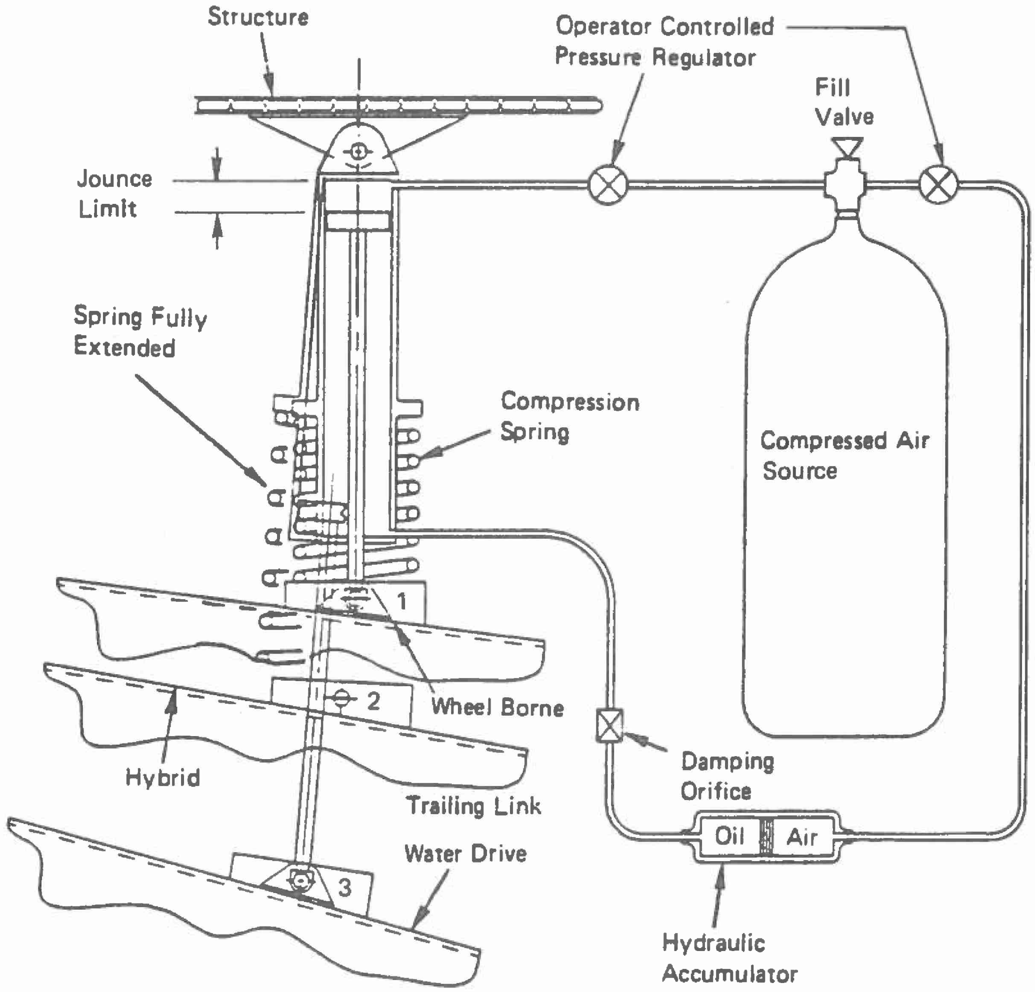


Figure 7-2. Oleo-Pneumatic Spring Strut

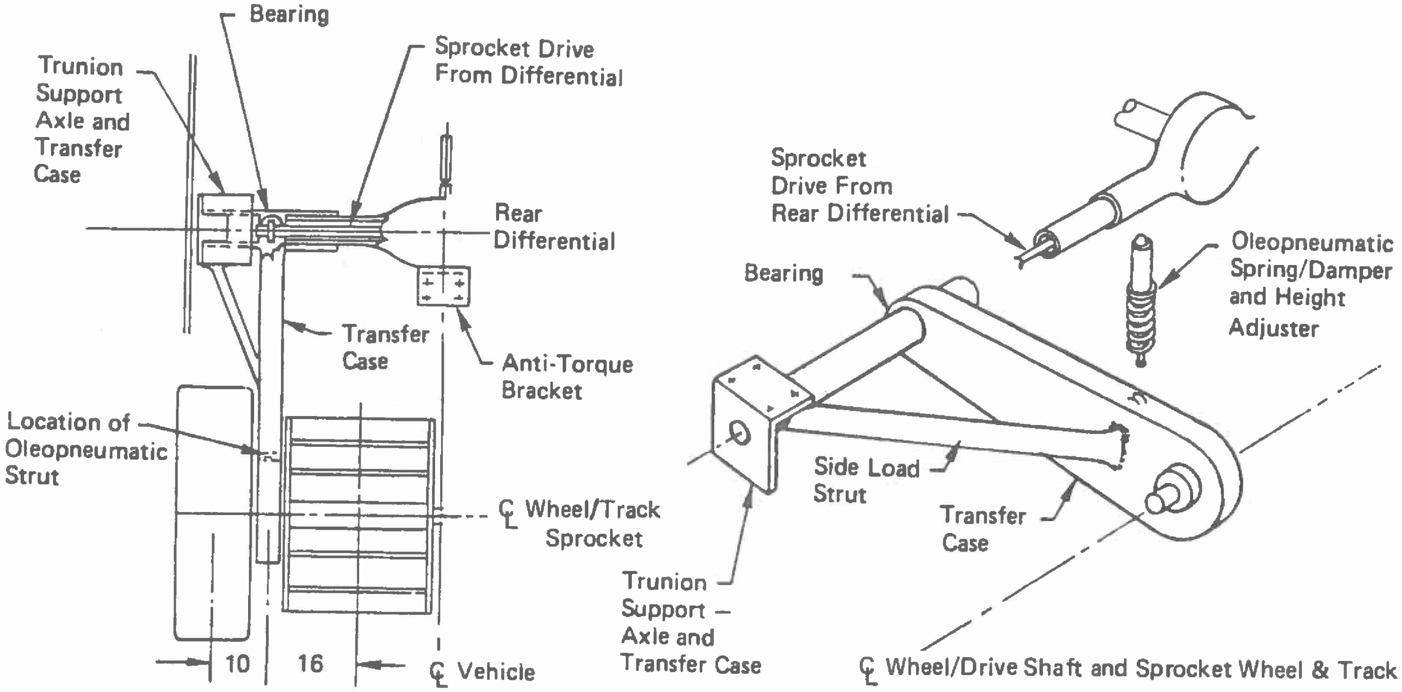


Figure 7-3. Rear Suspension Concept

jounce force works against the spring and the gas pressrue and the spring drive the wheel/transfer case down against the damping action of the oil being transferred to the hydraulic accumulator through the damping orifice. During waterborne operation while on cushion, the wheel/track system is extended down into the water to a centerline consistent with acceptable paddle track performance. Adjustment of the strut load to a constant value supporting the wheel weight is achieved by regulating the oil pressure. The lowest permissible position will be set by a full strut extension. For hullborne operations in the water the paddle tracks would be retracted to the region of normal land operation where good paddle track performance would result. Initial dynamic studies indicate good ride qualities using a spring rate of 1000 lb/inch and a damping factor of 0.5.

7.4 Flotation

Since the ACCRV must operate over water its flotation must be suitable for both cushionborne and for hullborne operation. The requirement for the latter is to provide safety for the crew/rescued personnel in the event of an engine malfunction. Since this provision is required, operation in the hullborne mode for close-in maneuvering can be used and may be preferable. Manuevering adjacent to a downed craft including full extension of the rescue boom within restricted zones is possible hullborne.

The ACCRV structure is watertight, providing inherent flotation in an emergency without use of the air cushion. The basic hull, with a volume of about 900 cu. ft. can displace 57,600 lbs. Considered by itself, the 30,000 lb. gross weight craft will float with a waterline about 3 ft. above the bottom of the hull, considering the buoyancy contributed by the wheels, tires and other submerged drive train components. Bilge pumps are provided to scavenge water entering through door seals and other hull penetrations. By this means the craft could be kept afloat in an emergency engine-out condition for a time possibly limited by bilge pump capacity and battery power. For reliable emergency protection, additional flotation may be added to stabilize the craft for hullborne rescue operation. It is achieved with very little weight penalty by designing the spray skirt as an inflatable bag, and is offered as an option.

7.4.1 Hullborne Operational Limitations

Operation of the ACCRV rescue boom in the fully extended position is limited to an arc segment of ±20 degrees forward when the craft is operated in the hullborne mode. An analysis performed using the Naval Ship Hull Characterization Program (SHCP), indicated that an overturn condition exists beyond the ±20 degrees limit because the fully extended boom produces unacceptable rolling moments which overcome the roll restoring moments required to prevent vehicle overturn. An ACCRV Vehicle Attitude map is shown in Figure 7.4.1 which illustrates the acceptacle boom angles versus boom extension in feet. Note: the limitation includes a ±10° safety margin. This attitude map was developed from pitch and roll restoring moment analyses obtained from the SHCP program. Roll restoring moment for roll angles up to 90 degrees is plotted in Figure 7.4.2 for two vehicle conditions, empty and loaded. A similar plot of pitch restoring moment is shown in Figure 7.4.3. The resulting boom moments in both pitch and roll, with boom extensions up to the maximum boom extension are shown in Figures 7.4.4 and 7.4.5. Configuration nomenclature for the various conditions are illustrated in Figures 7.4.6 and 7.4.7. In summary, it was concluded that vehicle operation between ±15 degrees forward, with boom fully extended in a horizontal plane is acceptable in the hullborne mode.

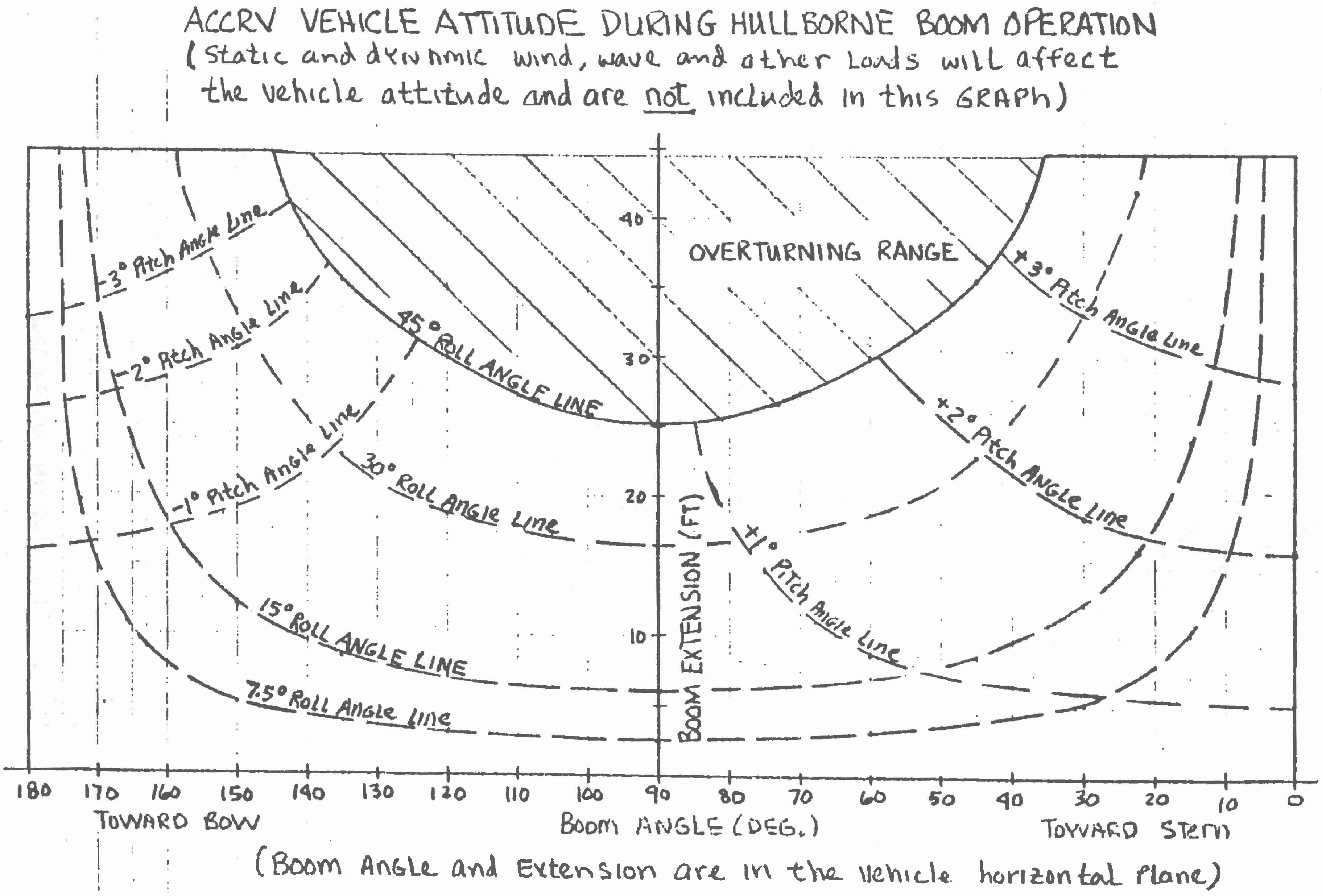


Figure 7.4.1 Vehicle Attitude Map

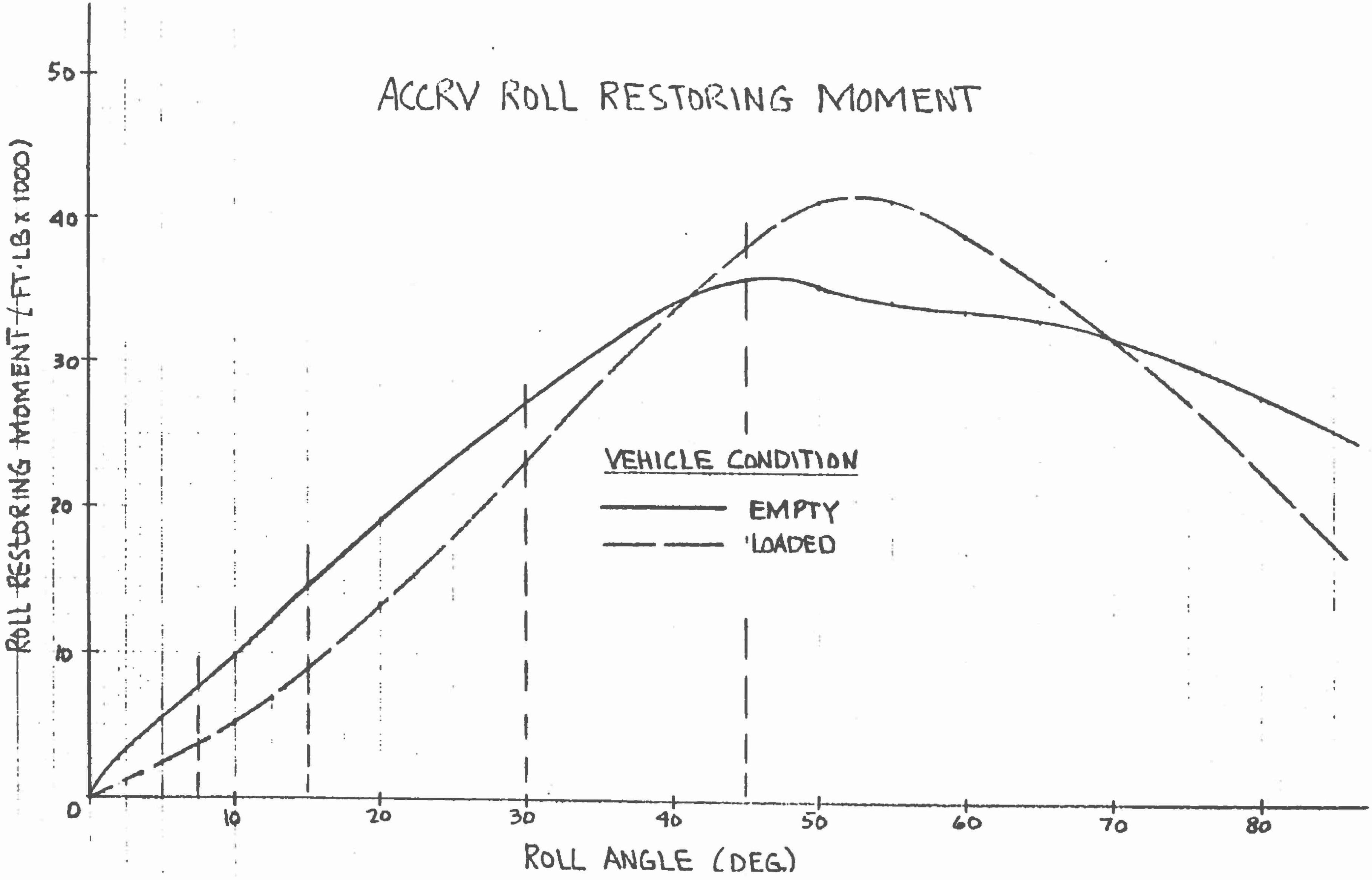


Figure 7.4.2 ACCRV Roll Restoring Moment

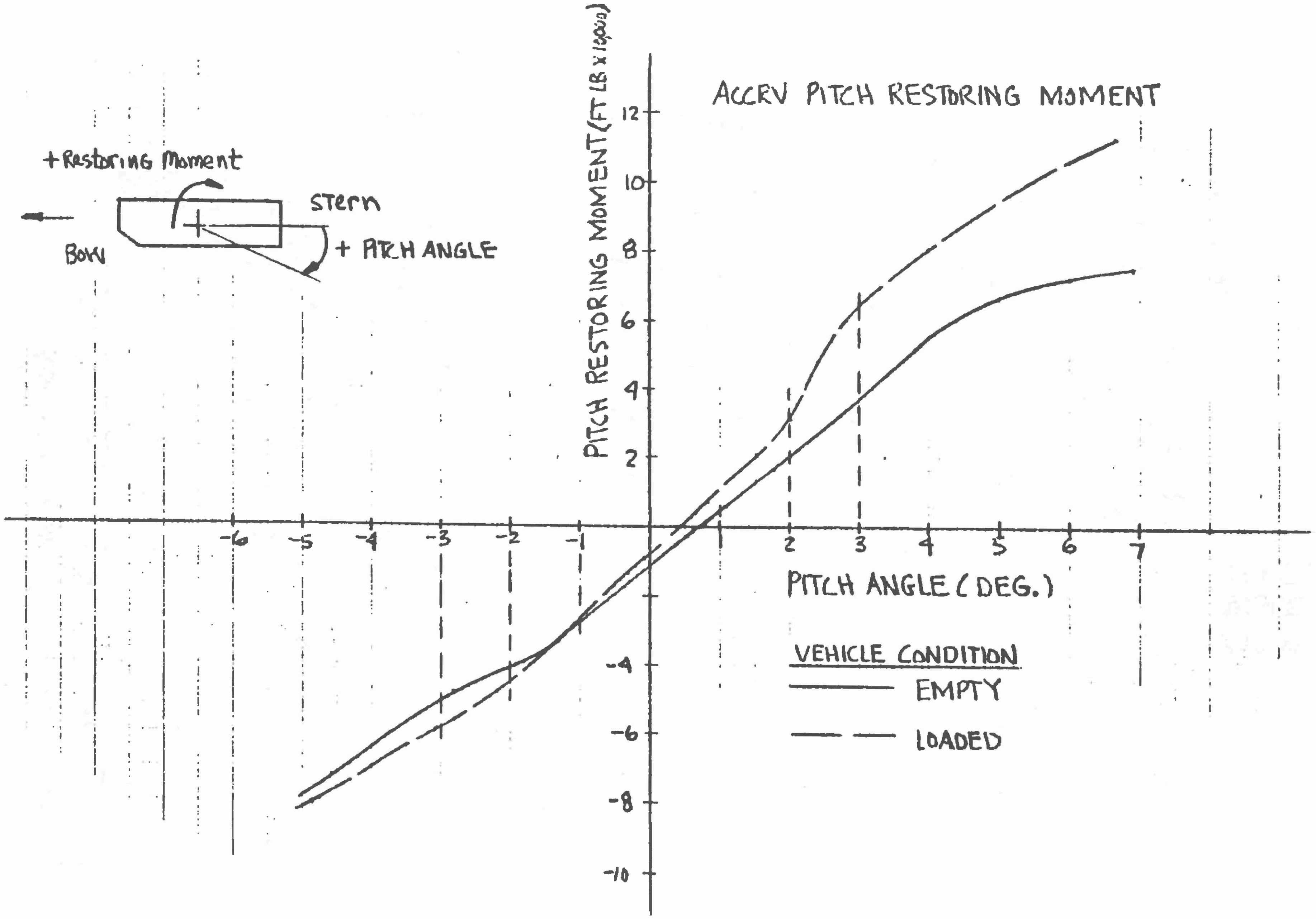


Figure 7.4.3 ACCRV Pitch Restoring Moment

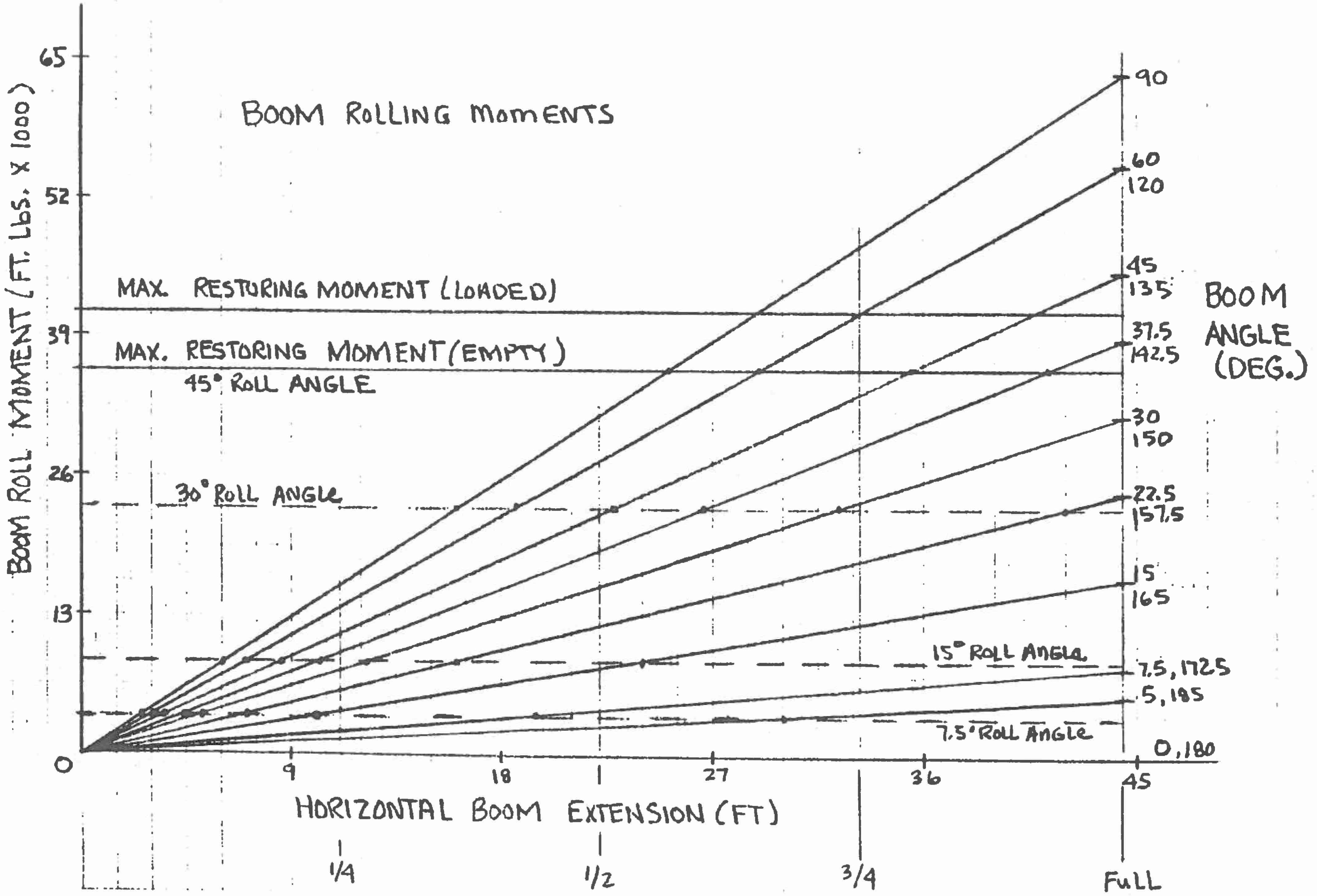


Figure 7.4.4 Boom Rolling Moments

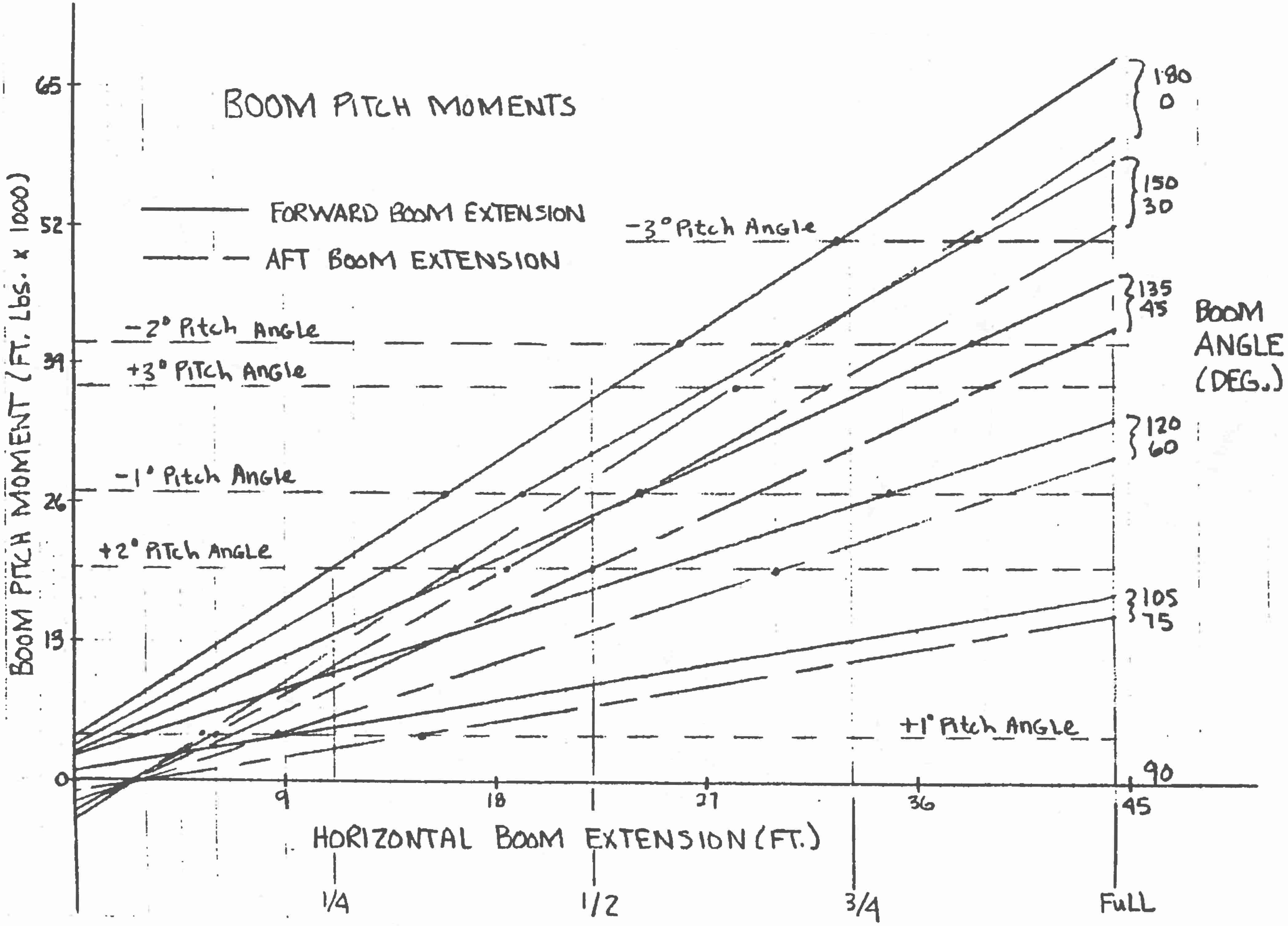
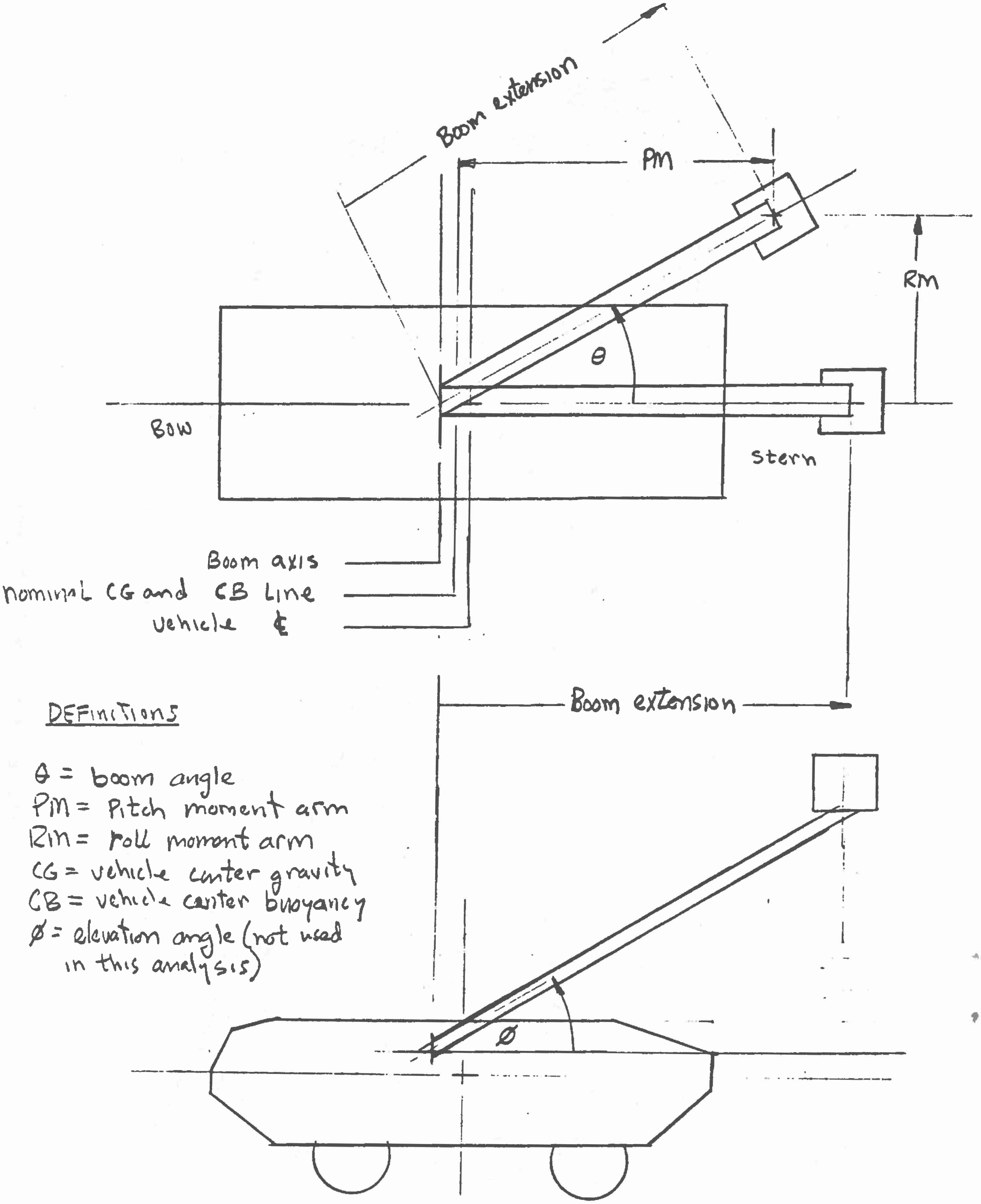


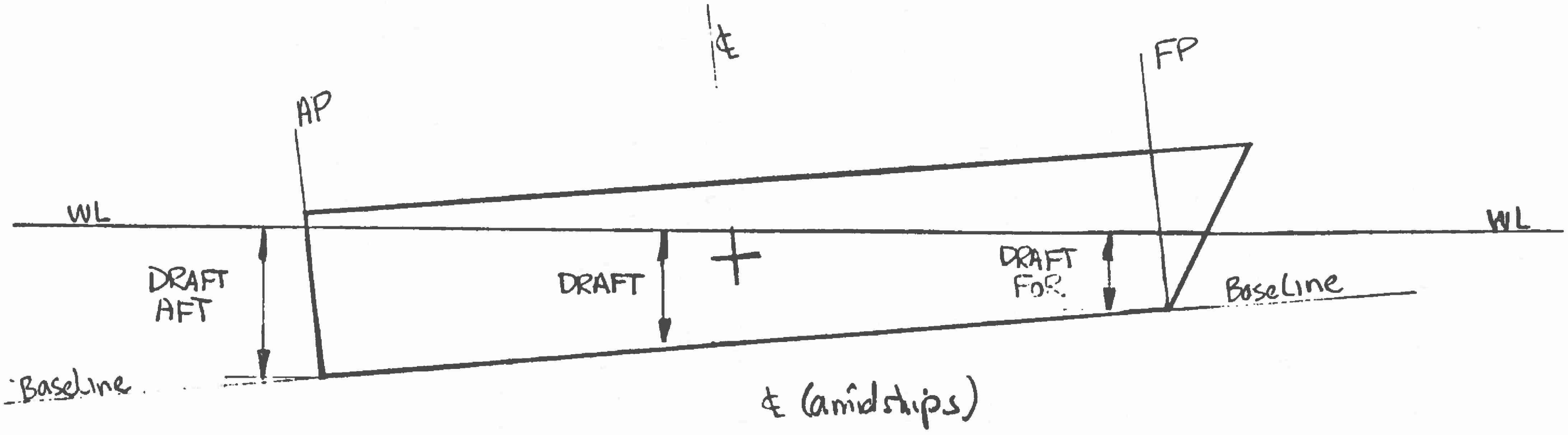
Figure 7.4.5 Boom Pitch Moments



DEFINITIONS

θ = boom angle
PM = Pitch moment arm
RM = roll moment arm
CG = vehicle center gravity
CB = vehicle center buoyancy
ø = elevation angle (not used in this analysis)

Figure 7.4.6 Boom Configuration



DEFINITIONS

AP- AFT PERPANDICULAR
FP- For PERPINDICULAR
WL- water line
DRAFT - water level above baseline, amidships
trim - draft at AP- draft at FP

Figure 7.4.7 Craft Nomenclature

8.0 AUXILIARY SYSTEMS

The auxiliary systems related to suspension/flotation include the following:

- Hydraulics to operate the brakes, power steering and the hydropneumatic struts
- Pressurization for the gas side of the hydropneumatic struts
- Tire inflation/pressure control system

8.1 Hydraulics

The brake hydraulic system is a standard configuration, self-contained, with a two compartment master cylinder. A schematic of the brake system is shown in Figure 8-1. One feature, somewhat unique to the waterborne operation is that the two zone system brakes diagonally opposite wheels. Selecting this concept for braking instead of front and rear pairs meets the land safety requirement and provides steering on water. Turning the steering wheel brakes one track while the other is still powered through the differential, offsetting the thrust vector to provide a steering moment.

The basic hydropneumatic circuit for wheel positioning and damping was shown in Figure 7-2. Both sides are supplied from a nominal 3000 psi source. A working pressure of 2000 psi is used for operation of the strut. The gas side accumulator prevents large increases in pressure during normal damper operation. Adjusting the regulated output pressure of the regulator will automatically rebalance the system to a new nominal wheel height. An orifice installed on the oil side is used to provide damping on the rebound stroke.

8.2 Tire Pressure Control System

During the Concept Definition phase, a remotely controlled tire inflation/pressure control system was baselined in order to improve the tractive effort produced by the wheels on marginal strength soils. While tire pressure control is known to provide this additional capability, the addition of tracks for mobility on marginal terrain renders the tire pressure control system an extra addition which adds to the vehicle cost.

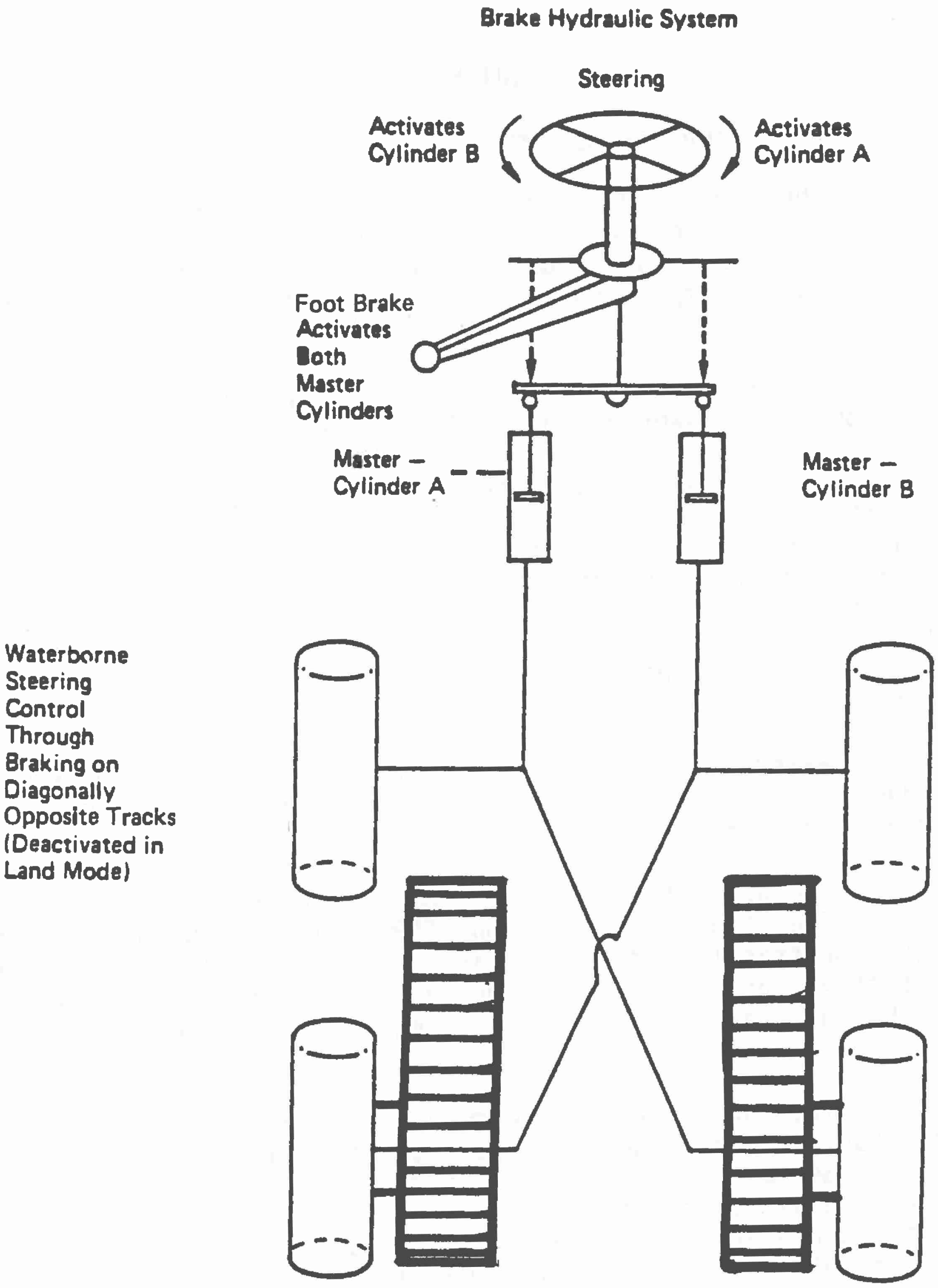


Figure 8-1. Braking/Water Steering System Schematic

9.0 EQUIPMENT

9.1 Fire Fighting System

The selected ACCRV configuration leaves intact all of the crash rescue and structural fire fighting capabilities of the P-19. Although the components are reorganized to make use of available space; they are standard components as used in current production type CFR vehicles.

Primary power for the system is taken from the engine flywheel through a power divider which allows pump and propel modes of operation for both land and water operations. A highly efficient and reliable around the pump type water/agent delivery system provides the superior performance needed for the ACCRV to accomplish its mission of controlling and extinguishing aircraft fires. A structural control panel with discharge and suction connections equip the vehicle to perform as a structural fire fighting unit.

The components and systems are described in the following paragraphs:

9.1.1 **Water Tanks** - Weight, space, and structural considerations have resulted in the selection of construction methods which integrate the hull and tank structures.

Because the hull is of monocoque construction, and inherently stiffer than a conventional CFR vehicle, the usual distortions which might be transferred to the tanks are eliminated, along with the usual protective tank mounting schemes and their inherent complexity and weight. Thus any tank, separate or integral, can be hard mounted to the hull.

The double wall honeycomb plates used to construct the hull are ideal for water and agent tank construction as well; this type of construction has been used by Bell in many applications where the main applied loads resulted from fluid pressures. Sensibly then, the hull and tank structures are integrated into a single unit. Integrity of design is insured by the NASTRAN modeling as discussed in Section 3.4.

Each of the twin tanks is provided with a removable, sealed inspection cover and access opening, 20 in. in diameter. See Figure 9-1. A Victaulic snap-on type coupling is used to connect/disconnect the vent-overflow loop from the inspection cover and vent/overflow pipe, when it is necessary to fill the tank or transport the vehicle by air. A four-inch vent/overflow pipe passes through the tank and directs excess water toward the vehicle centerline. The 5 inch vent/overflow loop has a 5 inch cap on one of the vertical legs, allowing it to be used as an emergency fill opening for a 2-1/2 in. hose. Both right and left tanks are identical and symmetrically equipped, having a net capacity of 500 gallons each. Fill,

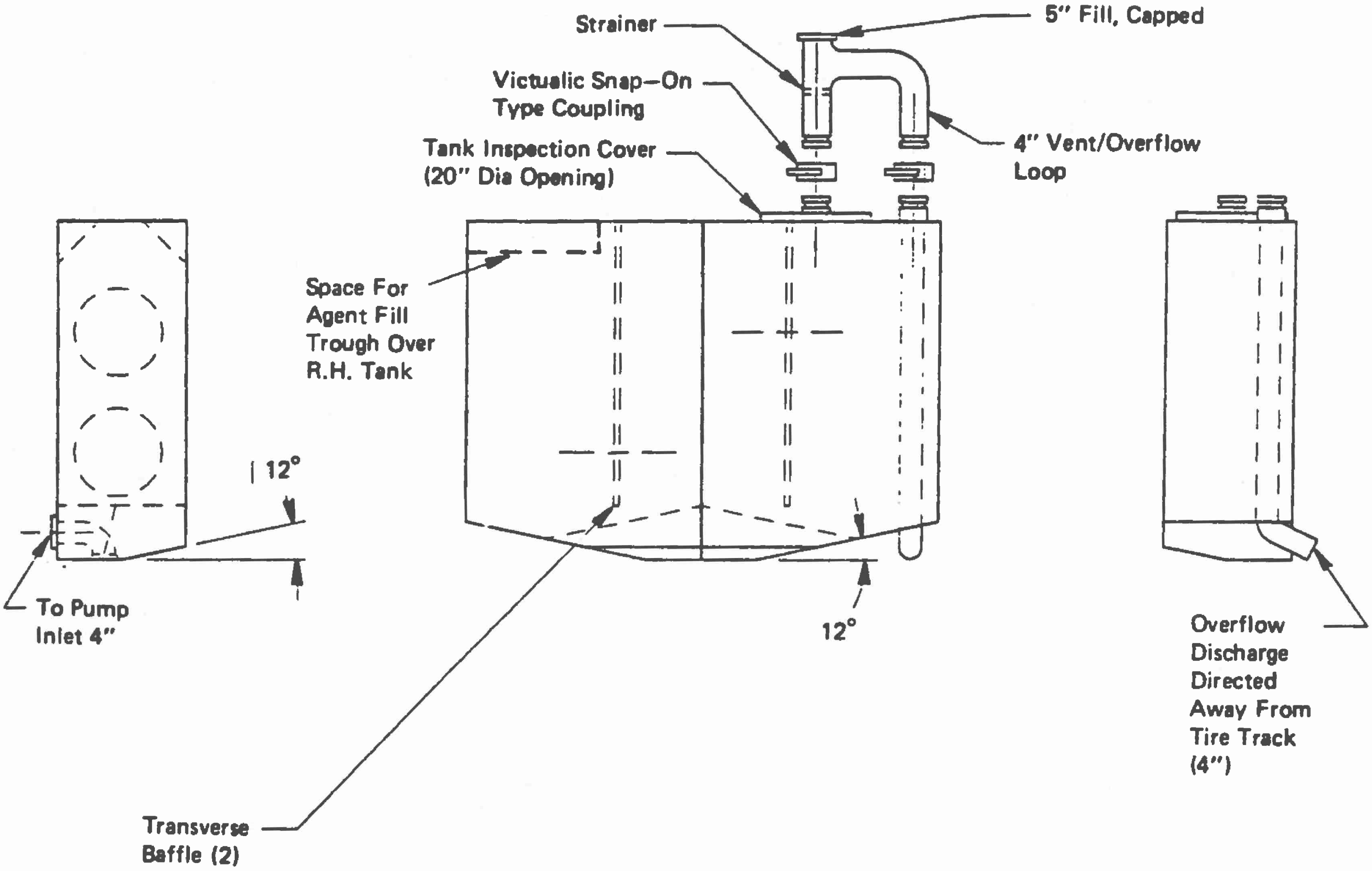


Figure 9-1. Water Tank Design

vent, overflow, and access functions have been combined to allow for top mounted storage compartments and the agent fill trough over the tanks.

Transverse baffles not more than 3 ft apart are used to limit rapid shifting of the water; the narrow width of the tank eliminates the need for longitudinal baffles. Twelve degree bottom surfaces are used to allow pumping at rated capacities while on 20% slopes. The completed tank, including the seals, will withstand an internal static pressure of 1 psig at the top of the tank without leaking. The double wall honeycomb panel sections used to construct the hull insure the tanks ability to withstand an internal tank pressure of 8 psig at the tank bottom.

To prevent corrosion and eliminate leakage due to bonding or weld faults, or structural cracking due to vehicle damage, the water tanks are fully lined with a rubber bladder, similar to those used on aircraft fuel tanks. The bladder is field replaceable for ease of repair or maintenance.

9.1.2 Agent Tank - The fire fighting liquid concentrate tank has a working capacity of 150 gallons which is sufficient to accommodate the discharge of 4850 gallons of water at a 3% agent concentration. A tank fill, vent, and overflow system is provided. Tank outlets are provided at the bottom of the tank for drainage and for supply to the proportioning system.

The location of the tank under the triage deck is ideally close to the pumping and proportioning system, minimizing agent loss upon shutdown. Access to the 20 in. diameter inspection cover is attained through the triage floor. Refer to Figure 9-2.

The fill trough, located behind the triage and over the water tank on the right side of the vehicle, has a hinged cover held closed by a quick release latching mechanism, and includes a 10 mesh stainless steel screen to prevent entry of foreign matter into the system. Knives, rigidly mounted to the trough, permit opening of the sides or bottoms of two five-gallon agent containers simultaneously. The screen and knife assembly is ruggedly constructed and readily removable. The fill and vent pipes, leading from the trough to the agent tank are routed along side the right hand integral water tank. The fill pipe is led through a bulkhead fitting and discharges near the bottom of the agent tank to minimize frothing. A vent tube leading from the top of the agent tank returns froth to the fill trough for recovery; excessive overflow is led to the ground through the use of an overflow pipe.

The agent tank also makes use of structural panels in the hull, and is bladder lined for the same reasons and in the same manner as the water tank.

9.1.3 **Pumps** - A HALE 60FJ4-U3000 single stage water pump is provided for the fire fighting system. The pump is located within the 48 inch wide engine compartment. The centerline of the pump inlet is approximately 16 in. above the centerline of the water tank outlets, a design feature employed satisfactorily in many commercial CFR vehicles. Power to the pump is from the engine flywheel, through a hydraulic clutch which may be engaged at any vehicle speed, and a drive shaft.

Capability of the pump in the application will be rated at 990 gpm at 225 psi with an impeller speed of 3000 rpm. Power consumption will be 187 horsepower in this condition. This pump was selected because of its simplicity of design and minimum number of components. An outline drawing and performance curve is included in Figures 9-3 and 9-4. The standard impeller for this pump is cast iron. Hale pumps with cast iron impellers will be used on prototype units. However, Hale will supply bronze impellers for production vehicles.

A priming pump is also provided. It is mounted beneath the main deck behind the cab, and is controlled from a combination switch and priming valve mounted on the outer control panel. The motor and pump, or the motor by itselt can be easily disconnected, serviced, or removed through an access door. An oil reservoir of at least 6 quarts is provided to lubriicate the pump; a drainage port is also provided.

Because of the closed hull design, an electrically driven bilge pump is installed in the pumping and proportioning compartment. The pump will be float actuated, and capable of keeping the hull free of water caused by minor fire system leaks, condensation, air conditioner drainage, and incidental water from top sides.

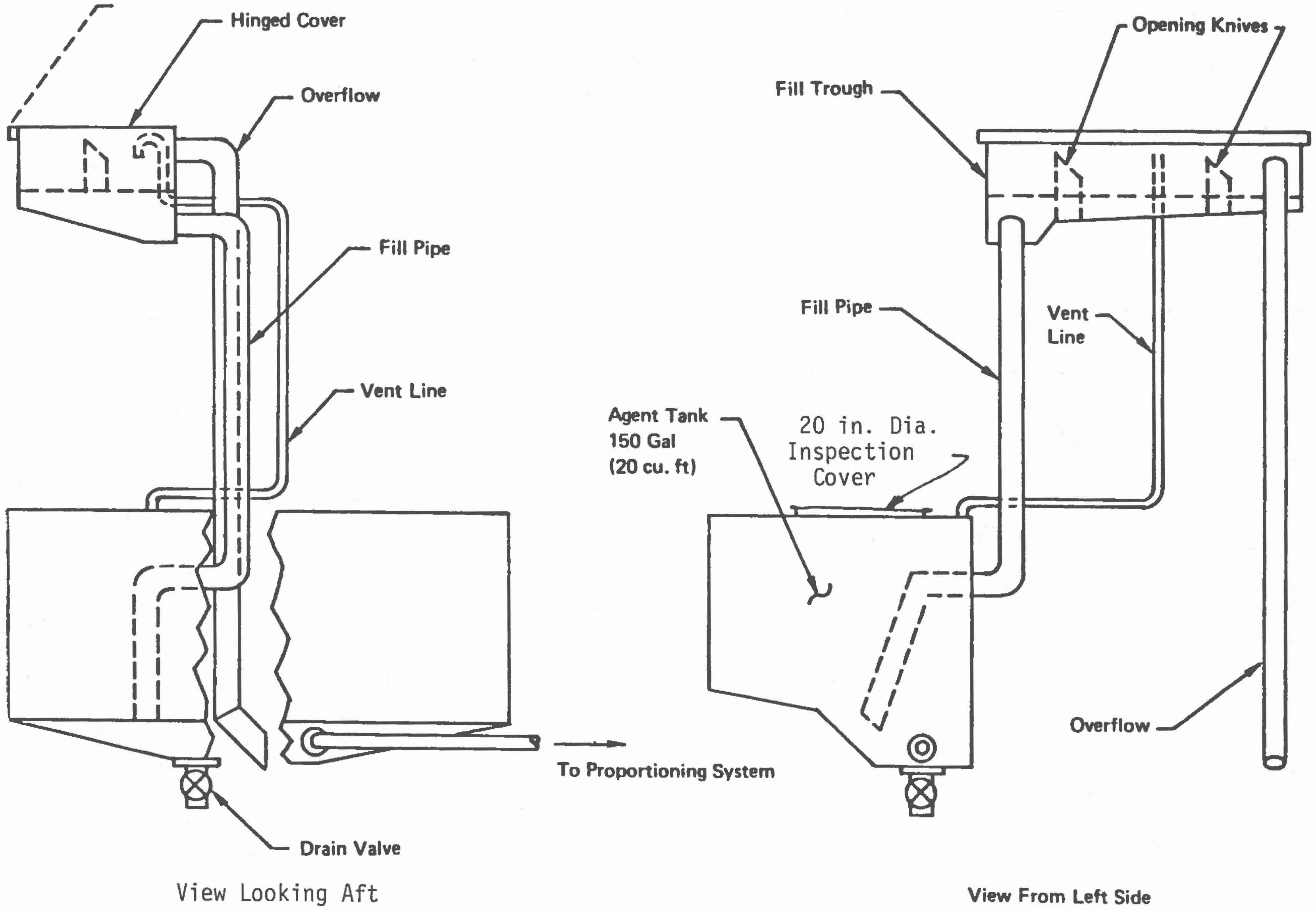


Figure 9-2. Agent Fill Trough and Tank

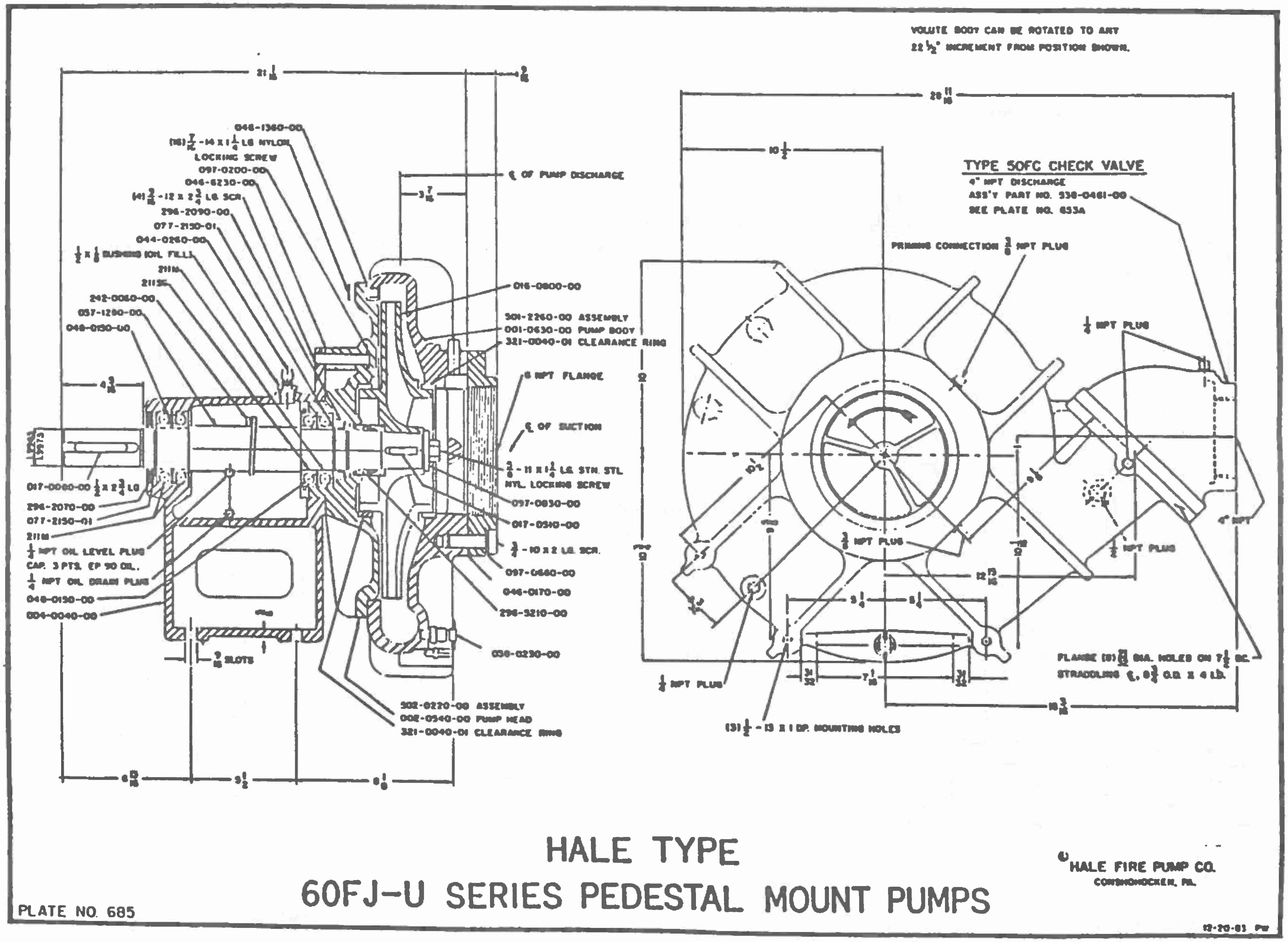


Figure 9-3. Hale 60FJ-U Series Pedestal Mount Pump

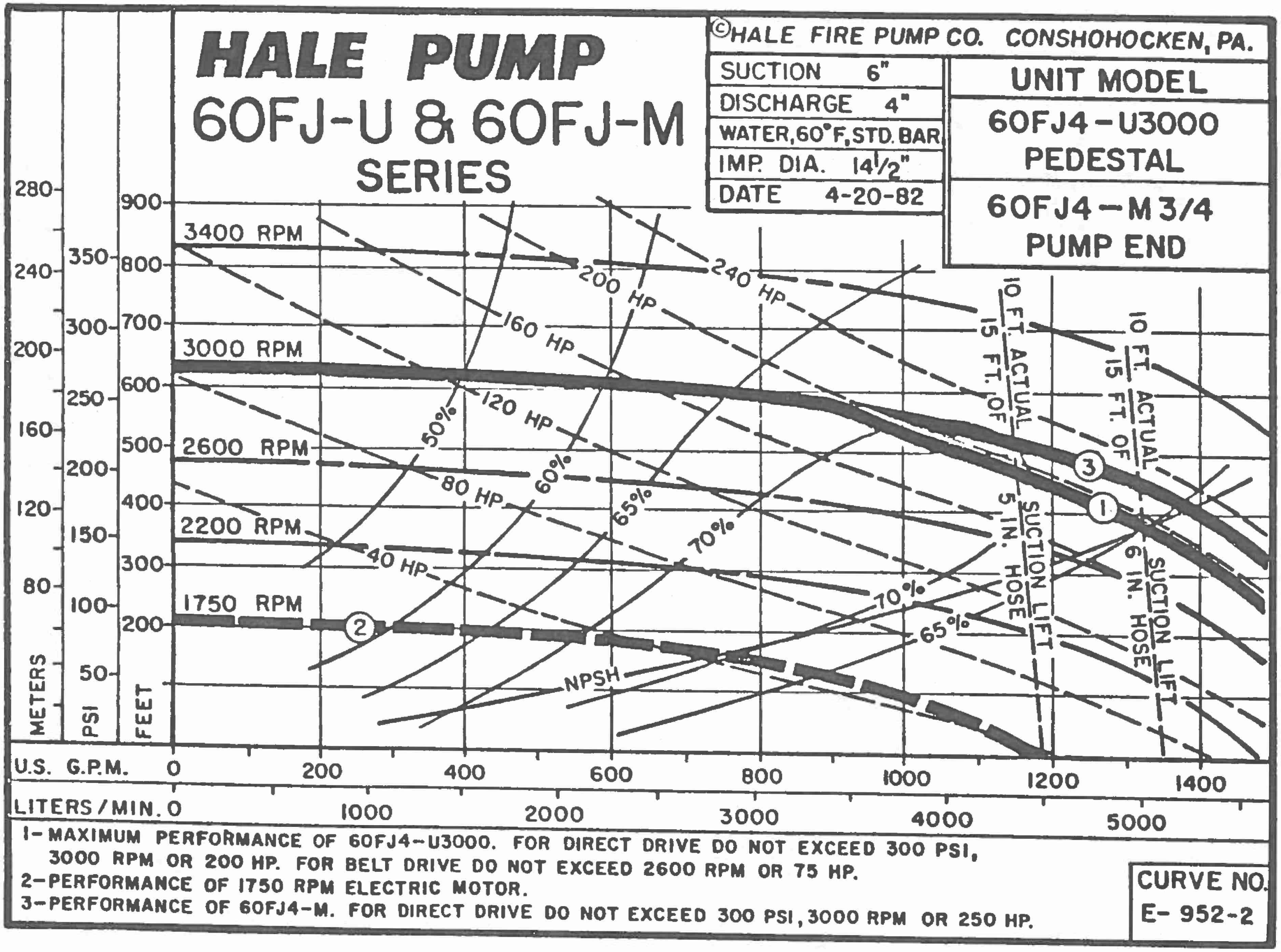


Figure 9-4. Hale 60FJ-U & 60FJ-M Pump Performance

9.1.4 Proportioning System - Reference is made to Figure 9-5 for the following discussion.

Water for the fire pump is drawn from the two water tanks through 4 inch combination shut-off and check valves into a 5 inch main feed line. Twin valves are used to limit water shifting from one side of the vehicle to the other under flotation or side slope operations. These valves also prevent contamination of the water tank with agent concentrate or agent/water mixtures should other system malfunctions occur. Water suppplied to the pump is raised to 225 psi for CRF operations, and 100 to 300 psi for structural work.

The fire pump discharge is divided among four separate circuits as appropriate, (a) pressure relief, (b) discharge from the ACCRV to the fire, (c) to the water tanks and (d) to the around-the-pump proportioning system.

The pressure relief and bypass circuit (A) returns excess flow to the pump suction when system pressure exceeds 240 psi for crash rescue operations, and any other preset pressure for structural operations. The relief valve control is mounted on the structural panel. The compact plumbing system, the around the pump proportioning system, and the pressure relief valve eliminate the need for other types of surge controls.

Discharge from the ACCRV (circuit (B)) to the fire is through three devices, a 500 (+50, -0) gpm turret, a 250 (+25, -0) gpm bumper turret and a 95(+5, -0) gpm handline, which may be used in any combination.

The roof turret is located on the right hand side of the vehicle on a hinge-down panel. The hinge down feature is used when vehicle height must be reduced for air transportability, a procedure requiring less than 15 minutes. Cab operation is preferred to keep the fire fighters out of the triage. Operation of the turret is remote from within the cab. Turret depression is 15 degrees, elevation 45 degrees, with rotation of at least 100 degrees each side of center. The turret discharge pattern is infinitely variable from straight stream to fully dispersed through the use of a remote control.

The bumper turret, located on the centerline of the ACCRV below the windshield line, is also controlled from a console positioned beside the driver near the front of the cab. The turret will have two modes of control: (1) Joystick Control - each individual turret motion is controlled by the operator by means of a power assisted directional control level, (2) Automatic Control - turret oscillates back and forth automatically.

An on/off push button switch is provided to activate the automatic oscillation control mode. The rate of oscillation can be set anywhere between 15 degrees per second to 30 degrees per second, the width of the sweep anywhere between 20 degrees and 90 degrees. The centerline of the oscillation pattern is adjustable anywhere within the range of rotation of the turret. The nozzle pattern and nozzle elevation are adjustable

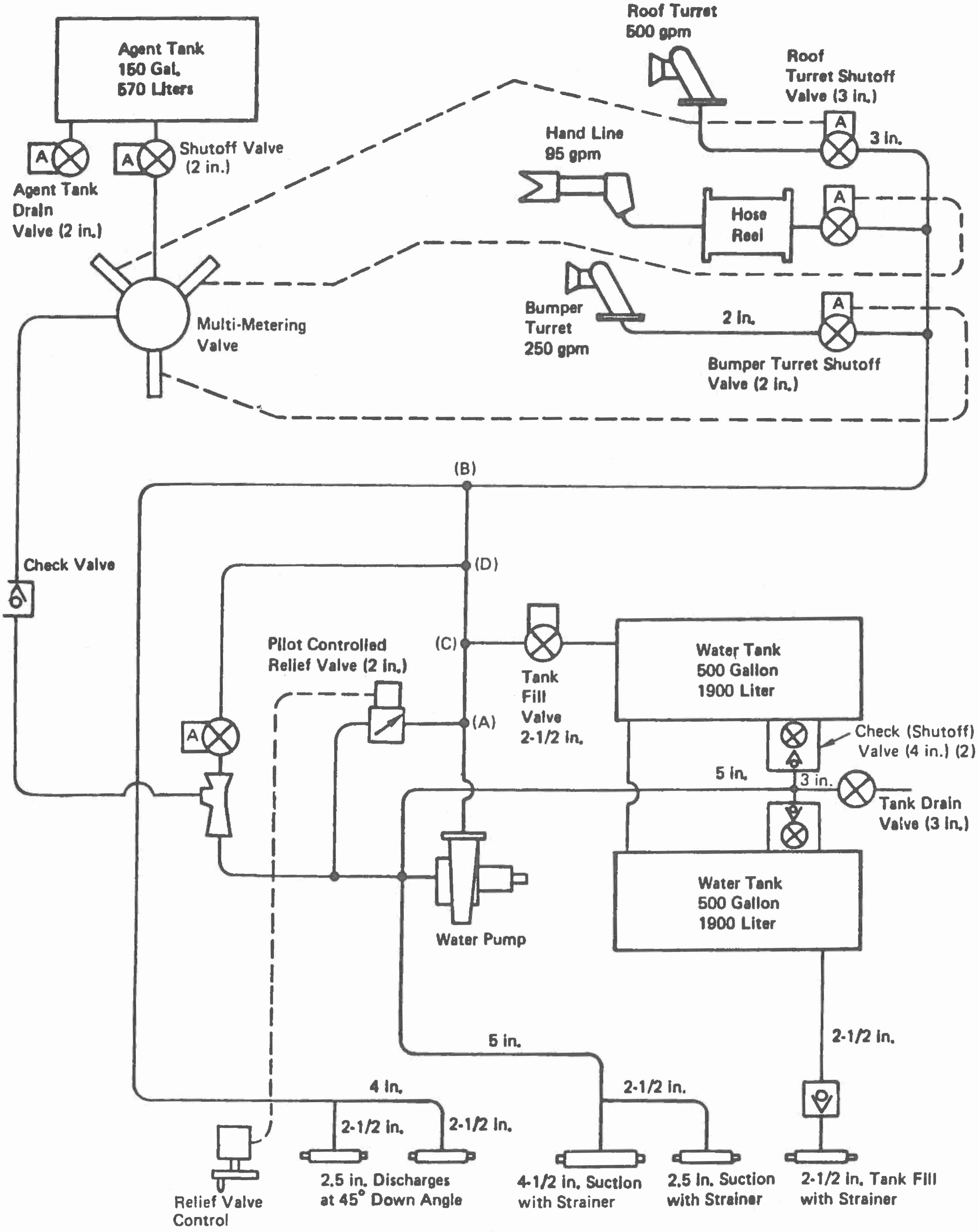


Figure 9-5. Pumping and Proportioning System Schematic

without interruption of the automatic oscillation movement. The turret can be depressed at least 20 degrees, elevated at least 45 degrees and rotated 90 degrees to either side of the straight ahead position. The pattern control will allow infinitely variable pattern settings from straight stream to fully dispersed.

The hose reel located directly over the right rear tire can be used from the right side of the vehicle or the top. The reel, with its bracket for the handline nozzle and guide rollers is mounted on a vertical pivot. Facing the side of the ACCRV, the handline may be deployed through the side door for ground use; facing the front of the ACCRV, the handline may be deployed through a deck access door and used on the rescue platform.

A reel with 100 ft, 1-1/4 in. hose capacity is supplied. The design of the hose reel assembly prevents dragging, snarling, and overrunning of the reel. Horizontal and vertical rollers reduce chafing and friction of the hose or catching of the couplings when the hose is being withdrawn. An electric rewind motor allows the hose to be rewound at a rate of 85 fpm. A manual rewind with features to minimize rewind motor drag is also provided. The electric rewind control switch is positioned to allow one person to activate and wind the hose onto the reel. The switch is located to protect it from interference from the hose. An air actuated 1/4 turn valve opens or shuts off the discharge flow. An air purge system control will purge any water or foam solution downstream of the discharge valve from the piping, hose, and nozzle to prevent freezing at low temperatures. A check valve in the purge system prevents water from entering the vehicles air system. The hose with a non-aspiring type nozzle attached will be capable of dicharging water or foam solution at a rate of 95 gpm (+5, -0 gpm) and will have a straight stream effective reach of at least 60 feet. It will not be necessary to clean the hose or nozzle after use at the scene of an emergency in order to accomplish rewind operations and storage. Lubrication fittings will be in accordance with MS 15003.

A provision is made to fill the water tanks directly from an external suction connection. To accomplish this, the tank shut-off valves are closed, the pump primed, and the tank fill valve opened, (circuit (C)) filling the tanks. A check valve in the agent tank supply line presents accidental contamination of the agent tank.

The proportioning system (circuit (D)) consists of three fixed orifices with shutoff valves piped in a parallel arrangement, around the pump water piping, and an agent eductor returning pressurized water to the pump inlet. The three fixed orifices piped in parallel are all contained in a single housing and called out as a multi-metering valve in Figure 9-5. (This is a standard component available from Feecon Corp.)

Water flowing through the eductor (venturi) draws agent into the flow which is subsequently mixed with the pump discharge water, most of which is expelled to the fire. The amount of agent drawn into the flow depends on the number of fixed orifices brought into play (1 to 3). One orifice/shutoff valve is dedicated to provide the proper amount of agent to the roof turret, one orifice/shutoff valve supplies the bumper turret, and one supplies the hand line. Each valve is controlled by an air signal when the corresponding discharge nozzle shutoff valve is actuated. When the roof turret is opened, the valve in the roof turret agent orifice line also opens. This logic also applies to the bumper turret and handline. Thus, agent supply is called for on demand, keeping the proper mix ratio. The system will provide agent concentrate ratios of 2.8% to 3.5% for 3% concentrate or 5.5% to 7% for 6% concentrate for the range of flows used in CFR operation, 60 to 845 gpm. In both cases, the orifice devices can be removed and exchanged to provide for the use of 3% or 6% agent concentrate.

Discharge and proportioning equipment will be provided by Feecon or Akron with preference given to those items currently in USAF inventory.

9.1.5 Piping, Connections and Controls - The unique configuration of the ACCRV concentrates and centrally locates all of the fire fighting system components except the structural outlets and control. Adjacent to the pump and proportioning compartment are: 1) cab with bumper and roof turret to the front, 2) agent tank to the right and, water tanks to the rear, and discharges and suctions to the left. This configuration decreases the lengths of wetted piping after tank shutoff valves, and pressure piping from the pump to the discharge, compared to standard CFR vehicles.

The compact pumping and proportioning configurations, coupled with the closed hull design, has several benefits. The amount of agent concentrate lost during system purge is minimized, winterization of the pumping system is easily accomplished, and pressure surges due to water inertia are mitigated.

Piping material will be 304L stainless steel; schedule 10 minimum, with efficient radiused turns to prevent pressure loss. Although the ACCRV hull provides a stiff platform for the fire fighting system, extensive use of Victaulic type couplings will be made to enhance maintainability and reduce corrosion rates by separating different types of materials.

In addition to the automatic drain valves on the bumper and roof turrets, a separate manually operated low point drain valve is provided for all piping, pumps, and wetted control lines. Careful attention will be paid to the installation of control lines to prevent "traps" or horizontal installations which will not drain within the allowable 4 minutes. Discharge of the drain valve will be beneath the ACCRV.

Structural connections and the control panel will be provided on the left side of the ACCRV above the left rear wheel. While this location is high for normal operation from ground level, if an air cushion failure occurs, or if the vehicle is deliberately put in the hullborne mode both the structural panel and connections will be above the water line. Use of this structural panel is convenient when the side sections of the air cushion are deployed, and the operator uses the cushion top deck as platform, placing all controls and connections within easy reach. Controls are mounted behind the panel, with full access to the back of the panel for service.

A second structural control panel which parallels all functions is located at the rear of the vehicle. This panel which is closer to the ground will be used when structural fires are fought with the vehicle in the wheeled mode.

Each structural control panel includes:

- a digital readout display for total flow
- flowmeters for both side discharges
- water pump relief valve control
- CFR or structural select switch
- priming pump control
- engine tachometer
- engine throttle control, air type
- engine oil pressure gage
- engine coolant temperature
- panel light controls
- tank shutoff valve control

The structural connection panel includes:

- two 2-1/2 in. discharges with caps and chains
- one 4-1/2 in. suction with long handle cap and strainer
- one 2-1/2 in. suction with cap and strainer
- one 2-1/2 in. tank fill with cap and chain

Operation of the ACCRV for crash fire rescue operations requires that the following cab controls and indicators be available to the driver:

- tank level gauges for agent and water
- autopump on/off
- agent tank on/off
- transmission shift lever
- accelerator pedal
- bumper and cab turret control panel (to be detailed at time of design)
- brake pedal
- steering system

9.1.6 **Winterization** - The winterization system will permit satisfactory operation of the ACCRV and fire fighting systems and provide required heating in ambient temperatures as low as -40 degrees F. The winterization system will be powered by an auxiliary power unit or the ACCRV electrical system and shall be designed to provide the required performance during all phases of vehicle and fire fighting operations regardless of engine speed. The system design and installation will include the necessary coolant flow shutoff features to permit the removal and reinstallation of the major components of the system without loss of coolant in excess of the capacity of the component being removed. The winterization system will be so installed and the vehicle so insulated that, after stabilization of operative temperatures, the system when operating in temperatures as low as -40 degrees F (with the winterization kit in operation), can be shutdown for a period of at least 2 hours without requiring the draining of the agent system and without freeze damage to the ACCRV and its components. Incorporation of the winterization features will not detract from the performance of the ACCRV or fire fighting system in normal or high ambient temperatures up to 125 degrees F. The winterization system will include but not be limited ot the following features:

a. Two coolant circulating pumps, one independent of the booster heater.
b. Diesel fueled booster heater.
c. Cab and compartment heating and ventilating system.
d. Fire system heat exchangers.
e. Water recirculating pump.
f. Engine heating system.
g. Control system.

The winterization system provides for forced flow of coolant solution through a closed circuit with an electrically driven coolant pump. The booster heater transfers heat from its boiler to the coolant as it is being circulated. The coolant, through heat exchangers, distributes this heat to the cab heater and defroster, the pumping and proportioning compartment, the hose reel and battery compartments, the engine cooling system has an expansion tank with filler opening and drain readily accessible for inspection and servicing. The capacity of the expansion tank is adequate to assure that all coolant lines will remain full if the coolant system is allowed to cool at a temperature of -40 degrees F. Reference is made to Figure 9-6.

A 24 vdc centrifugal type coolant pump is used to circulate the coolant through the booster heater circuit. The pump size assures the proper temperature differential between the input and output temperatures as recommended by the booster heater manufacturer when using winter coolants. The coolant circulating pump is equipped with ball bearings to assure a long life expectancy, and satisfactory operation at -40 degrees F. A flow switch is incorporated in the coolant system to monitor the flow of the coolant pumped; in event of a pump failure, an impulse will be sent to a relay which in turn will blow the vehicle's horn.

A booster heater using diesel fuel and operating on 24 volts dc, conforming to MIL-H-4697 requirements will be supplied. The heating capacity supplied will result from a study of the ACCRV in its final configuration. The heater will be located in the hull behind the rear axle in a partitioned compartment also housing the battery boxes. Access to the heater is from the top deck. Acceptable heaters are manufactured by Janitrol, Webasto, Espar, and Benmar; final selection will be made during the detail design stage.

All necessary controls for the operation of the booster heater will be provided. The booster heater can be activated from the cab. Circuits integral with the booster heater include thermostatic control of the boiler heat and overheat/shutdown protection. Automatic switches will be provided to shut down the booster heater in event of an overheat problem or an ignition failure. If these types of failures occur, a signal would be sent to a relay which in turn would blow the vehicle's horn.

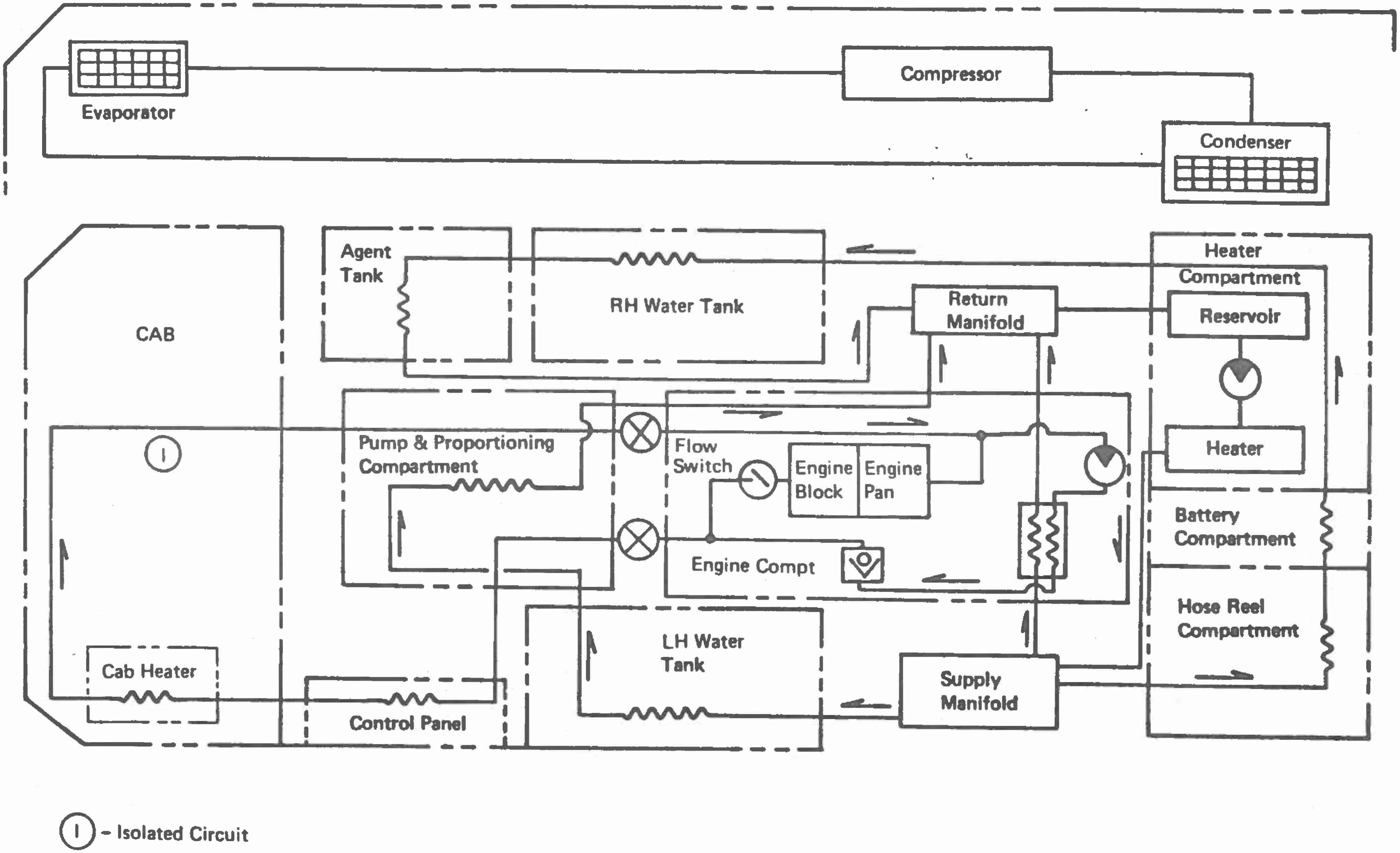


Figure 9-6. Winterization Schematic

The booster heater's exhaust is directed up and towards the air cushion fan intakes to prevent damage to equipment due to radiation or conduction of heat. The location of the booster heater on the vehicle precludes the possibility of exhaust fumes entering the cab or reverse drafts from entering the heater exhaust pipe and causing a malfunction. Drain lines connected to the water jacket of the booster heater allow draining of the coolant to the outside of the vehicle.

The heating and defrosting systems are adequate for four persons in the cab and four in the triage compartment. The fresh air intake, capable of 120 cfm and normally located low on the cab, will be located near the roofline to avoid taking in water in the hullborne operation.

The cab and triage compartment heater will contain a heater core, dampers, and damper controls to allow mixing of the inside with outside air to any degree desired ranging from total air recirculation to total fresh air ingestion. The electric motor driven blower mounted inside the heater housing will blow the inducted air over the heater core and through the defroster ducting to distribute it evenly over the transparent glass areas in the cab anc through ducting to controllable registers near the floor in the partition between cab and triage area on each side of the door. A multispeed motor control will be provided to control the velocity of the air flow. Adequate heating capacity will be provided to maintain a cab floor temperature of +40 degrees F and a clear glass area of 75% of the total surface, when the cab and triage compartment are occupied by eight people and the outside temperature is -40 degrees F.

Tube and fin heat exchangers are used in two compartments, the pumping and proportioning compartment, and the partitioned heater, battery, and hose reel compartment. The exchangers will be sized to maintain 40 degrees F at the compartment floors.

All of the fire system discharge piping not automatically drained on shutdown is located in the heated pumping and proportioning compartment, eliminating the need to recirculate heated water through all wetted piping. A recirculating water pump is provided for the water tanks, taking water from the bottom of the tanks and returning it to the tank tops. This circulation is separate from an auxiliary heater flow, which is through heat exchangers located in the bottom of the water tanks.

A separate coolant circuit is provided to transfer engine heat to the structural control panel and vehicle cab, as shown diagrammatically on Figure 9-6. Two features are added to the conventional arrangement to allow heating of the circuit without the engine running. First, an electrically operated coolant pump instead of the engine coolant pump, circulates the coolant and second, a heat exchanger is added to transfer heat from the booster heater circuit into the isolated circuit.

When using the booster heater, the engine and cab/control panel are in parallel circuits appropriately balanced to heat the cab and engine to required temperatures. When operating the main engine, the cab circuit is in series with the engine, and the auxiliary circulating pump is shut down by the flow switch on the engine to heater output port, avoiding inadvertent overheating of the engine. This design will assure the standby and starting performance specified without affecting the engine's normal cooling and lubricating systems. The heating system will be adequate to maintain engine temperatures required to assure engine starting within 15 seconds in temperatures as low as -40 degrees F.

Cab controls for the winterization system shall be as follows:

- start/stop switch for booster heater
- fan control and heat regulator for cab heater
- water tank recirculating pump switch
- red indicator light to signal booster heater failure

9.2 Triage Area

9.2.1 Configuration - The triage area is located directly behind the cab, over the agent tank, pump and proportioning compartment, and extends from the left to the right side of the vehicle (see Figure 9-7); access doors are provided on the left side. This location provides excellent access to the cab and communications equipment, assuring optimum coordination of medical and rescue operations; it is also located away from the engine and lift fans, keeping noise interference to a minimum.

The working deck in the triage area is approximately five feet below the ACCRV top deck, and offers some protection to the injured and crew. When not in use, the rescue boom platform covers the triage compartment for added protection. Equipment storage cabinets are provided for medical supplies. The right hand compartment door in Figure 9-7 is bottom hinged and serves as a work surface when opened. It is anticipated that the medical attendant will use the seat over the left hand wheel well, thereby being in a position to observe the injured personnel.

As a possibility for reducing weight and gaining more space for the internal subsystems, the enclosed triage area could be eliminated. Stretchers could then be placed on the side cushion platforms, which would be down for operations on air cushion over adverse terrain. If the cushion is already retracted, then other rescue vehicles will be in the area.

An additional benefit of removing the triage area and its associated equipment, is a savings in vehicle cost.

9.2.2 **Emergency Medical Equipment** - The List of medical equipment that follow is typical of that carried on an ambulance, and will be provided.

Qty	Descripton	Wt (lb)	H x L x W (in.)	Comments
3	Cardiac Monitors	9.55 ea	3.8 x 13.3 x 5.7	Battery Incl.
1	DC Defibrillator	11.90	3.8 x 13.3 x 9.2	Battery Incl.

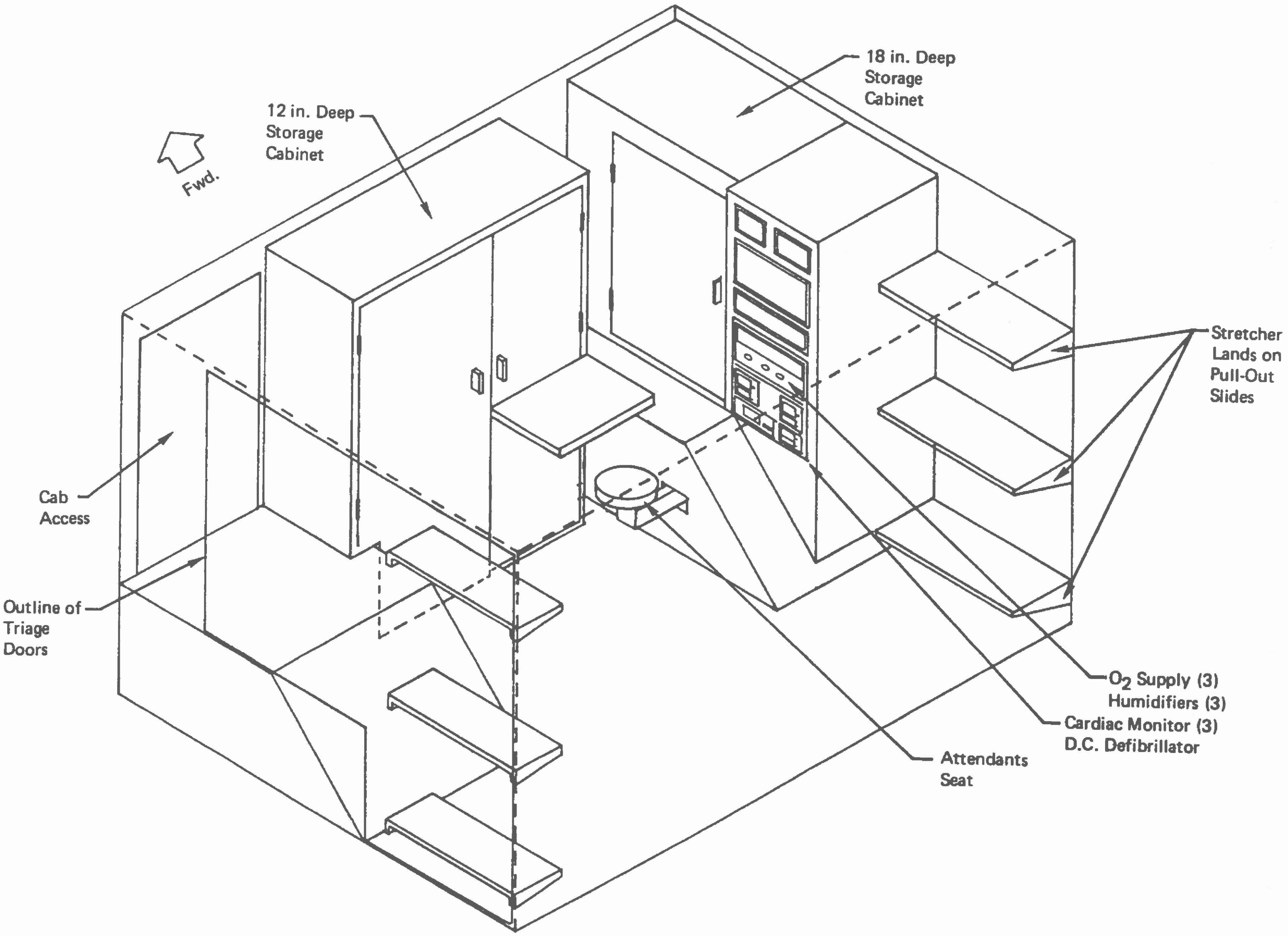


Figure 9-7. Triage Layout and Stowage

Qty	Descripton	Wt (lb)	H x L x W (in.)	Comments
1	I.V. Infusion Pump	2.75	7.2 x 4.3 x 5.0	Battery Incl.
3	Electronic B.P. Cuffs	7.75 ea	2.7 x 5.6 x 5.5	Battery Incl.
1	CPR Thumper	25.3	6.0 x 30.5 x 26.0	
2	Alum. D-Size O_2 Cylinders with Yoke	7.35 ea	4.0 x 30	For use with Thumper
1	Drug Kit	13.65	22.5 x 8.5 x 18.0	Soft-pack
1	Airway Kit	10.50	18.0 x 10.0 x 16.5	Soft-pack
1	I.V. Kit	16.50	22.5 x 10.0 x 16.5	Soft-pack
1	Truma Kit	12.75	22.5 x 8.5 x 18.0	Soft-pack
3	Medical Anti-Shock Trousers with Single Gauge	6.65 ea	8.5 x 9.60 x 16.0	Size when folded into soft-pack
3	Traction Splints	3.60 ea	3.5 x 50.25 x 10.5	
3	Burn Packs	3.35 ea	6.0 x 10.5 x 14.0	Soft-pack
1	Air Splint Kit	2.85	4.0 x 18.75 x 19.5	Soft-pack
3	Medium Cervical Collars	0.35 ea	8.0 x 5.0 x 6.0	
3	Large Cervical Collars	0.40 ea	8.5 x 5.5 x 6.5	
3	Blankets	1.00 ea	6.0 x 4.0 x 10.0	Folded
1	Installed Suction Venturi System	-		
1	Installed O_2 "H" Cylinder Aluminum	37.5	9 x 48	Can be placed outside of compartment

Qty	Descripton	Wt (lb)	H x L x W (in.)	Comments
3	Cardboard Backboards	0.75 ea	0.35 x 78 x 20	Disposable
3	O_2 Humidifiers	1.05	5.0 x 3.5 x 3.5	
	Total Weight 234 lb.			

NOTE: Installed O_2 system will have 3 outlets with humidifier, one at the head of each patient.

In addition to the above, three stretchers of 6 ft. 6 in. length can be stowed on the stretcher mounts. The oxygen cylinder, size H, will be secured as weight and space requirements dictate.

9.2.3 Triage Access

Stretcher lift from the ground in the wheeled mode is performed by two (or more) attendants, one of which steps onto the extendible step located just behind the forward left wheel as shown in Figure 9-8. Once upon the step, he must lift his end of the stretcher up into the triage compartment through the previously opened door. Two attendants inside must assist in moving the stretcher to the lowest available stretcher shelf, especially if more injured are to be carried. The attendant on the exterior step must take the other end of the stretcher from his partner and lift it up into the compartment in the transfer procedure. When the air cushion is deployed, the operation is the same except that the first attendant stands on the side panel instead of the extendible step. When this panel is deployed, the lower triage access doors can be opened, thus reducing the lift height to the triage compartment. Full scale mockup tests of these arrangements must be accomplished to assure that the atten-

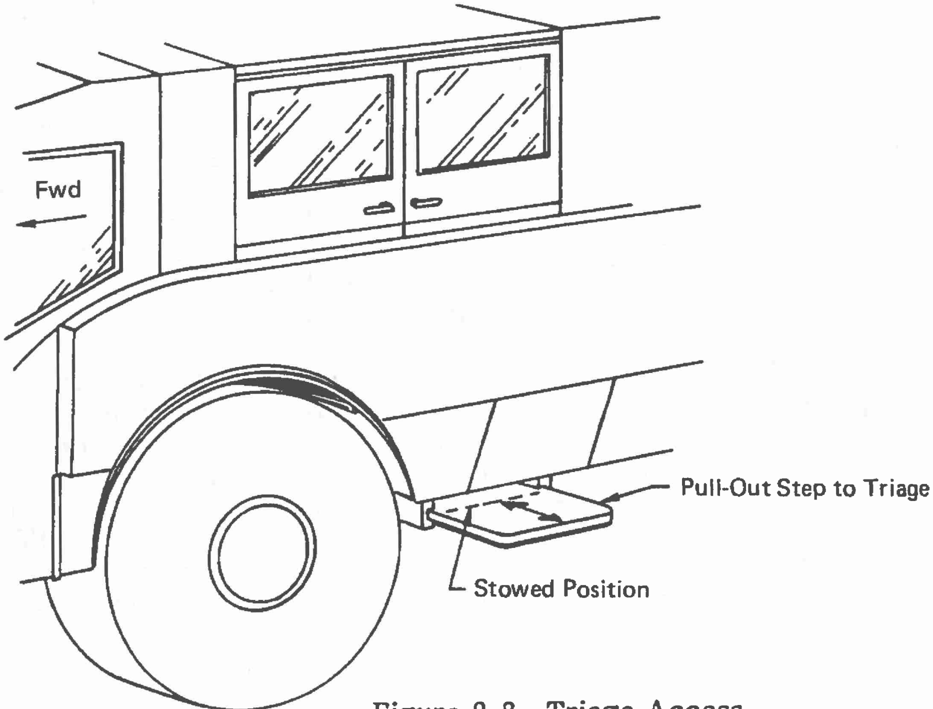


Figure 9-8. Triage Access

dants can accomplish these tasks. If not possible, the solution is to install a jib crane of about 1000 lbs. capacity which can lift and rotate the stretchers from the ground and into the triage compartment. This solution is not incorporated now due to the additional weight and cost that would be incurred.

9.3 Rescue Boom, Slide and Equipment

9.3.1 Rescue Boom - The selection of a rescue boom type and location was based on three perceived needs: 1) to reach any cockpit emergency exit of all aircraft in the USAF inventory on land or water, 2) to allow quick access to the triage deck for injured personnel, 3) to be able to perform a rescue at the water surface. Weight and space constrictions required the lightest and most compact arrangement available.

The rescue boom selected is of the articulated arm type, primarily because it can reach over the front of the vehicle and can be reasonably extended away from the hull. Note that a large weight and cost saving can be gained if the boom can be redesigned without the kink and telescoping end.

The boom is mounted amidships directly behind the triage area and over the transmission. This position was selected to allow for two platform positions, either even with the top deck and over the triage area or adjacent to the triage area over the top deck. Access to the platform for rescue personnel is from the cab through the triage area. Transfer of injured personnel from the platform to the triage area is readily accomplished with the platform in its aft position.

The length of the articulated boom which can be stowed within the profile constraints gives an overall extended length of 41 ft. An upper boom telescoping section increases this reach to 44.5 ft. With the boom extended over the front of the cab and the centerline of the platform directly over the front face of the cab, platform height will be approximately 51 ft. from hard ground. The platform can also be placed at the water surface with the front edge of the platform up to 30 ft. 9 in. from the front of the cab (Figure 9-9).

The rescue boom may be used on firm surfaces or over water in the hullborne mode with side panels deployed. Under these conditions, the range of the rescue boom is limited to plus/minus 15 degrees of forward. Operation of the boom in the air cushion mode could lead to instability under some conditions and is therefore not permitted. An option in the hullborne mode is to use inflated buoyancy bags as part of the spray skirts to increase the range of boom travel.

An available boom configuration meeting weight and configuration constraints has not been located. However, a specially designed unit, manufactured from sections of fiberglass and carbon fiber is being designed. This design does not meet the original weight allocation of 575 lbs., but will meet the configuration restraints. The weight allocation for the boom (listed in the weight tables of Section 2.2.3) is 995 pounds, The emergency slide (an additional 150 lbs.), is currently attached directly to the rescue platform. Present payload on the rescue platform is

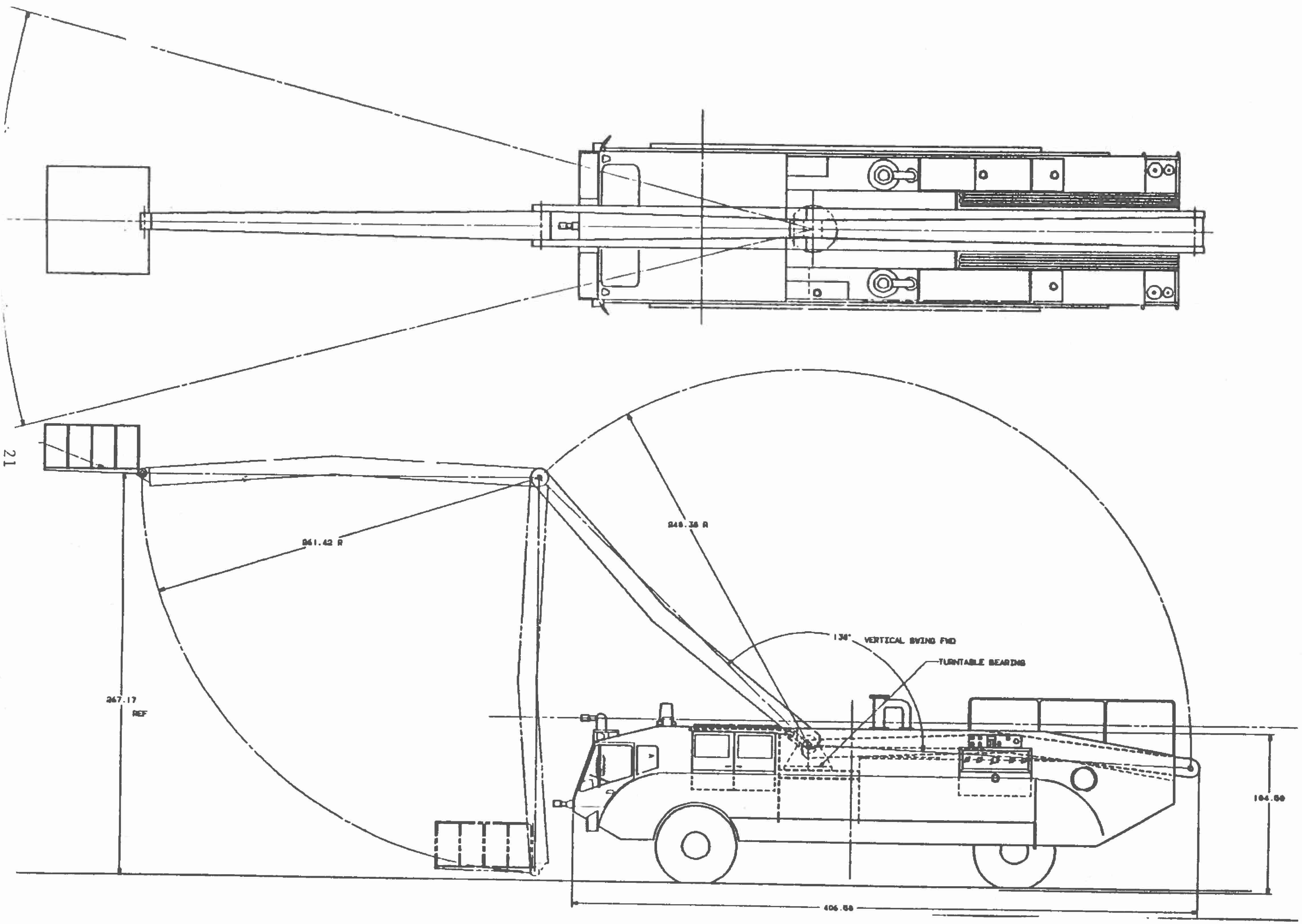


Figure 9-9. Boom Extension

estimated to be 1100 pounds, consisting of two injured personnel, an attendant, and the emergency slide equipment.

The rescue platform is equipped with appropriate handrails which can be removed and stowed on the triage deck for air transport and an emergency slide (Section 9.3.2). Boom controls will be duplicated, i.e., a control panel will be located near the triage area, which is paralleled with a boom control panel attached to one of the rescue platform handrails. In the event of control malfunction or an inability of the rescue crew to use the platform mounted control, the boom can be lowered or operated by the triage area control.

Relative motion between the waterborne ACCRV-rescue boom and the aircraft is inevitable. It is necessary that rescue personnel be able to secure the rescue platform to the aircraft, and that the boom not become a rigid link between the aircraft and the ACCRV. Therefore, provisions are made in the boom control system to "float" the boom such that linking forces are kept within the boom's structural capability, and restoring forces are such that the ACCRV hull and the rescue platform tend to remain in the same relative positions. Relative position holding is also necessary for rescue slide use.

9.3.2 **Slide** - An inflatable single lane slide, similar to aircraft evacuation slides currently used on commercial jets flying today and the C-5A will be provided on ACCRV. The inflatable slide will be stored on and deployed from the side of the lift platform to allow quick disembarking of crew and personnel.

The upper end of the slide is attached to the floor of the boom platform. Its 72 foot length is sufficient to reach the ground at an angle of approx. 45 degrees, when it is deployed from the ACCRV platform raised to the maximum height attainable by the boom (50 ft. from ground level).

Inflation of the slide is by means of an integral aspiration system containing pressurized gas or CO cartridges which are triggered when the slide is deployed over the side of the platform. Inflation time is about 10-15 seconds. Recent improvements to aircraft escape systems include radiant heat resisting materials and deployment capability in 25 knot winds. Both features are desirable and will be included in the ACCRV slide. Provisions are also made at the platform attachment points to permit ditching the slide when quick response is demanded for retrieval and hospitalization of seriously injured personnel.

Current estimates for the weight of a 72 foot long single lane slide and inflation system are in the order of 232 lbs. This estimate is predicated on use of current state-of-the-art technology for slides used on commercial aircraft.

Based on the current weight estimate of the emergency slide, which results in a reduction in boom payload, it is recommended that the emergency slide be deleted from the Crash Rescue vehicle.

10.0 STABILITY AND CONTROL

10.1 Wheelborne

10.1.1 Wheelborne Stability

Stability in the wheelborne mode is provided by the wheel/suspension system characteristics and proper wheel base and wheel tread. A combined tire/suspension stiffness of 12,000 lb/ft per wheel or 48,000 lb/ft total has been selected for the design. This stiffness results in an undamped natural heave frequency of 1.14 and 1.47 hertz at the loaded and empty weights, respectively. The wheel dampers have been sized to provide a damping coefficient of 1668 lb/fps per wheel or 6672 lb/fps total. This provides a damping ratio of 0.5 and 0.65 at the loaded and empty weights, respectively. These frequencies and damping ratios are typical for vehicles that must operate both on and off road and were selected based on BAT's experience with wheeled and tracked armored vehicles.

With a wheelbase of 202 inches, the vertical suspension provides a pitch stiffness of 54,900 and 56,300 ft lb/deg at the loaded and empty conditions. At upward end wheel lift off, this results in maximum restoring moment of 240,900 and 146,300 ft lb at the loaded and empty weights, respectively. With a wheel tread of 85 inches, the roll stiffness is 7900 and 9200 at the loaded and empty weights and the maximum restoring roll moment is 79,900 and 55,200 ft lb at the loaded and empty condition. The maximum restoring moments at loaded weight provide adequate margin for boom operation at full extension in all quadrants. At empty weight, they provide adequate margin in pitch for full fore/aft boom extenson but are somewhat marginal in roll for full side boom extension. Because of this, the air cushion skirt side panels must be extended as outriggers when using the boom.

For operation on side slopes, the ACCRV roll stiffness provides static stability on slopes with up to a 52% grade at the loaded weight and to a 74% grade at the empty weight condition.

10.1.2 Wheelborne Control

Steering control in the wheelborne mode is provided through front wheel steering. Independent suspension on a common front axle that acts as an "I" beam and proper selection of castor and camber angle insures high speed steering and cornering stability. Tight turns can be negotiated at low speeds yielding a wall to wall turning diameter of 1200 inches or 2.9 vehicle lengths.

10.2 Waterborne

10.2.1 Cushionborne Mode Stability

Heave Stability - The heave dynamics of an air cushion suspension system are represented by a third order characteristic equation instead of the second order equation that is typical for wheeled suspension system. The additional dynamic order for an ACV is due to the compressibility of the air in the cushion. This results in a lag in the air cylinder type damping from the cushion. The damping phase shift due to this lag is destabilizing and becomes more significant as the lag increases and/or as the heave stiffness increases. Bell and others have shown that the air cushion system becomes unstable whenever the compressibility lag time constant exceeds the characteristic stiffness time constant. This has led to the development of a heave stability index for ACV's of the form,

$$\mathrm{HSI} = \frac{\gamma\, P_c\, h_{gap}}{h_c\, Q} \left[\frac{Q}{2P_c} - \frac{\partial Q}{\partial P}\,\mathrm{fan} \right] \geq 1 \text{ for stability}$$

where h_c = cushion depth

h_{gap} = gap height under cushion

P_c = gage cushion pressure

$\overline{P}_c$ = absolute cushion pressure

Q = cushion flow

$\frac{\partial Q}{\partial P}$ = fan slope

γ = process exponent (approximately 1.2 over water, based on tests)

Analysis of the ACCRV with this index shows that a conventional open finger seal with a uniform gap height could result in heave instabilities when operating the vehicle over a smooth, flat surface. The heave stability index in this case is 0.55 for 100% fan rpm and 0.75 for 70% fan rpm. To avoid this possibility over smooth water, the effective gap height on the ACCRV has been increased significantly by incorporating a series of air lube holes near the lower tips of the open fingers. By spacing these holes over a finger depth of about six inches and sizing them to nominally pass the 100% rpm cushion flow, the ACCRV must move down 6 inches to shut off the cushion flow rather than just the air gap height of only 0.75 inch. This makes the effective air gap look like 6 inches and reduces the vertical stiffness by the ratio of 6 over 0.75 or by a factor of 8.

The heave stability of the ACCRV with this finger design is 3.9 at 100% fan rpm and 5.3 at 70% fan rpm. Bell experience has shown that there is more freedom to modify the effective gap height than any of the other ACV design parameters that influence stability. Modifying the gap height with finger lube holes was tested on the full scale Bell Air Cushion Equipment Transfer (ACET) and found to radically improve heave stability without any significant adverse effects on drag.

Static Attitude Stability - Static attitude stability of the ACCRV is provided by the large inward taper of the bottom or skin face of the knee-shaped open fingers. High inward taper is obtained without sacrificing cushion area by the use of these knee type open fingers that cant outward at the top and then inward at the bottom. This results in a large increase in finger contact area and outward cushion center of pressure (CP) shift on the fngers that move downward as a result of any attitude change. As an example, right hand side down roll of the ACCRV results in a large increase in the contact area on the right hand skirt fingers and a restoring shift in cushion CP to the right. The predicted static pitch and roll stability with these fingers is shown in Figure 10.1 and 10.2, respectively. As shown in these figures, the stiffness increases more slowly at first. This is because an ACV initially rotates about the cg until an air gap is created on the upward side that is large enough to pass the cushion flow. After this, an ACV tends to rotate about the upward side and the stiffness increases more rapidly. This continues until the finger is immersed to the knee at which point the stiffness starts to decrease rapidly. For the ACCRV, this occurs at about 3.5 deg. in pitch and 5.5 deg. in roll. The maximum ACCRV pitch stiffness at this attitude is more than adequate for dynamic pitch stability. As shown, the ACCRV pitch stiffness results in static pitch trims of 1.8 and 2.5 degrees for the loaded and empty conditions respectively, both of which have longitudinal cg's aft of the cushion cp. While the roll stiffness of the single cushion, open finger ACCRV is somewhat lower than that for most existing ACV's with multiple cushion compartments and/or closed fingers, analysis indicates that it is more than adequate for the relatively low speed, low wave height operating environment for the ACCRV. Neither the pitch or roll stiffness of the ACCRV on cushion, however, is adequate for operation of the rescue boom. For this operation, the ACCRV must go into a displacement mode to provide adequate stability.

10.2.2 Waterborne Control

Waterborne steering control of the ACCRV in both the cushionborne and displacement modes is provided by using the independent aft wheel brakes to brake the wheel/paddle track on the side in the direction of the desired turn. This causes the braked paddle track to slow down and produce less thrust and the unbraked paddle track to speed up and produce more thrust. The differential thrust produces a yawing moment that turns the vehicle in the desired direction. Maximum control power is obtained by braking one paddle track to a stop. This causes the other paddle track to speed up as required to absorb the horsepower available. Except for some change in efficiency with speed, the thrust produced with the speeded up paddle track is essentially the same as that for both unbraked paddle track at the same horsepower. Thus, the maximum yaw control power available is roughly equal to the thrust times the lateral distance from the cg to the paddle track centers. The ACCRV has good control power at the on cushion cruise thrust. At lower speeds, good control power levels can be obtained by temporarily increasing the thrust level towards maximum thrust during control maneuvers. This also applies to the low speed displacement mode.

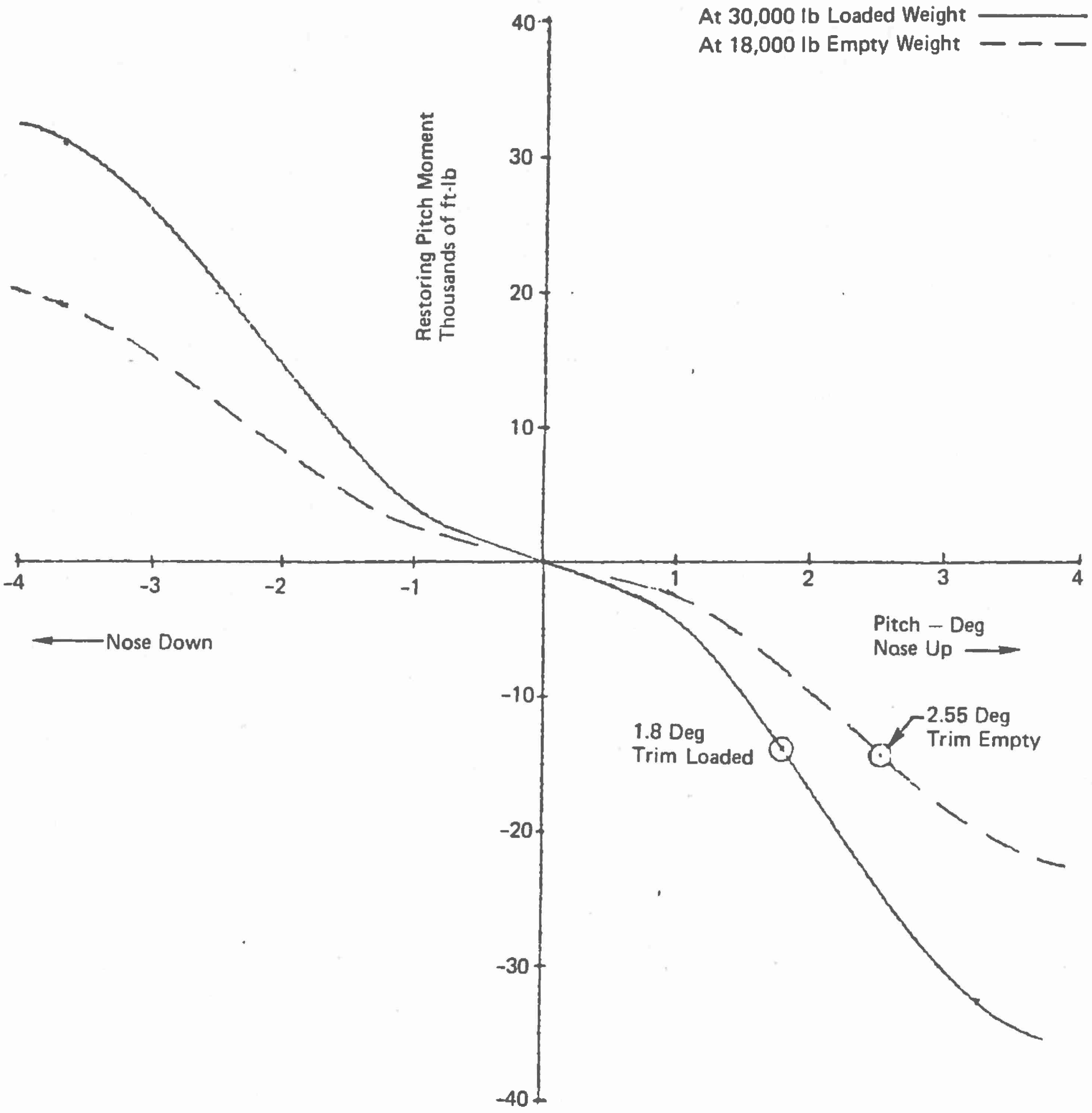


Figure 10.1 Static Pitch Stability - Overwater Cushionborne Mode

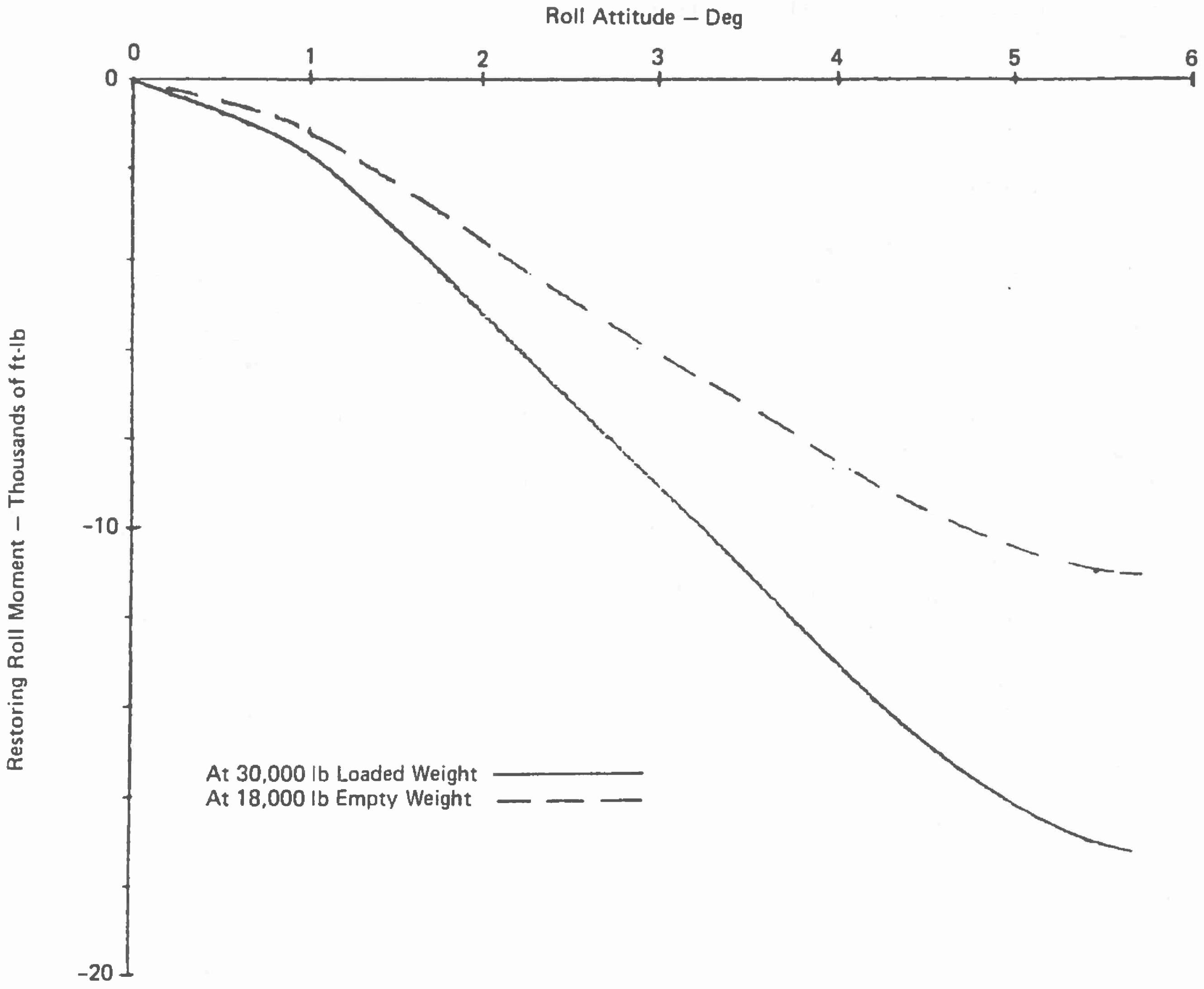


Figure 10.2 Static Roll Stability - Overwater Cushionborne Mode

Since the front wheels of the ACCRV are driven and steerable, it may be possible to obtain some additional low speed control power at the front end of the craft by proper selection of a tire design/tread that produces some thrust in water. This possibility was not investigated during this program.

10.3 Hybrid

10.3.1 Hybrid Stability

Heave Stability - ACCRV stability in the hybrid mode was studied using the hybrid suspension model illustrated in Figure 10.3. Linearized root locus analysis of this model indicates that both the air cushion and wheel suspension contribute to provide stabile operation over the full range of hybrid conditions of interest. This is shown in the root locus plots in Figure 10.4 for wheels that are actively controlled to carry a constant percentage of the vehicle weight without wheel springs and dampers active and for wheels that also have active springs and dampers for the nominal hybrid wheel load case of 30%. The pair of imaginary roots that lie above and below the real axis in this figure are associated with the conventional second order rigid body suspension dynamics mode. They result primarily from the combined stiffness and damping of the air cusion and wheel suspension systems. The fact that they are off the real axis indicates that this mode is less than critically damped. In this case, the damping ratio is proportional to the inclination (from the horizontal) of a radial line from the original to the root. The root on the real axis results from air cushion compressibility dynamics. As shown, the hybrid system is quite stable with all roots well removed from the unstable right hand plane. The air cushion alone (0% weight on wheels) is stable and carrying increasing percentage of vehicle weight on the wheels (without suspension stiffness and damping) further improves the stability by moving all roots further away from the unstable right hand plane. It also improves the damping of the system as indicated by the movement of the pair of imaginary roots closer to the real axis.

Studies on the influence of adding wheel stiffness and damping independently have shown that adding wheel stiffness alone results in a significant decrease in damping but only a small decrease in stability margin. Adding wheel damping alone results in significant improvements in both stability margin and damping. Adding wheel stiffness and damping together as required to keep the wheelborne heave damping ratio constant results in a significant increase in stability of the second order rigid body suspension mode and a slight decrease in the stability of the cushion compressibility mode. Damping of the rigid body mode is essentially unchanged because the roots tend to move out on a radial line from the origin. The roots at a wheel suspension stiffness of 48,000 lb/ft are representative of operation at normal wheel extension. Those at a stiffness approaching zero are large enough to go beyond the normal rebound range of the wheel springs. This could happen during operation in deep snow and during ditch crossing.

Attitude Stability - The static attitude stiffness in the

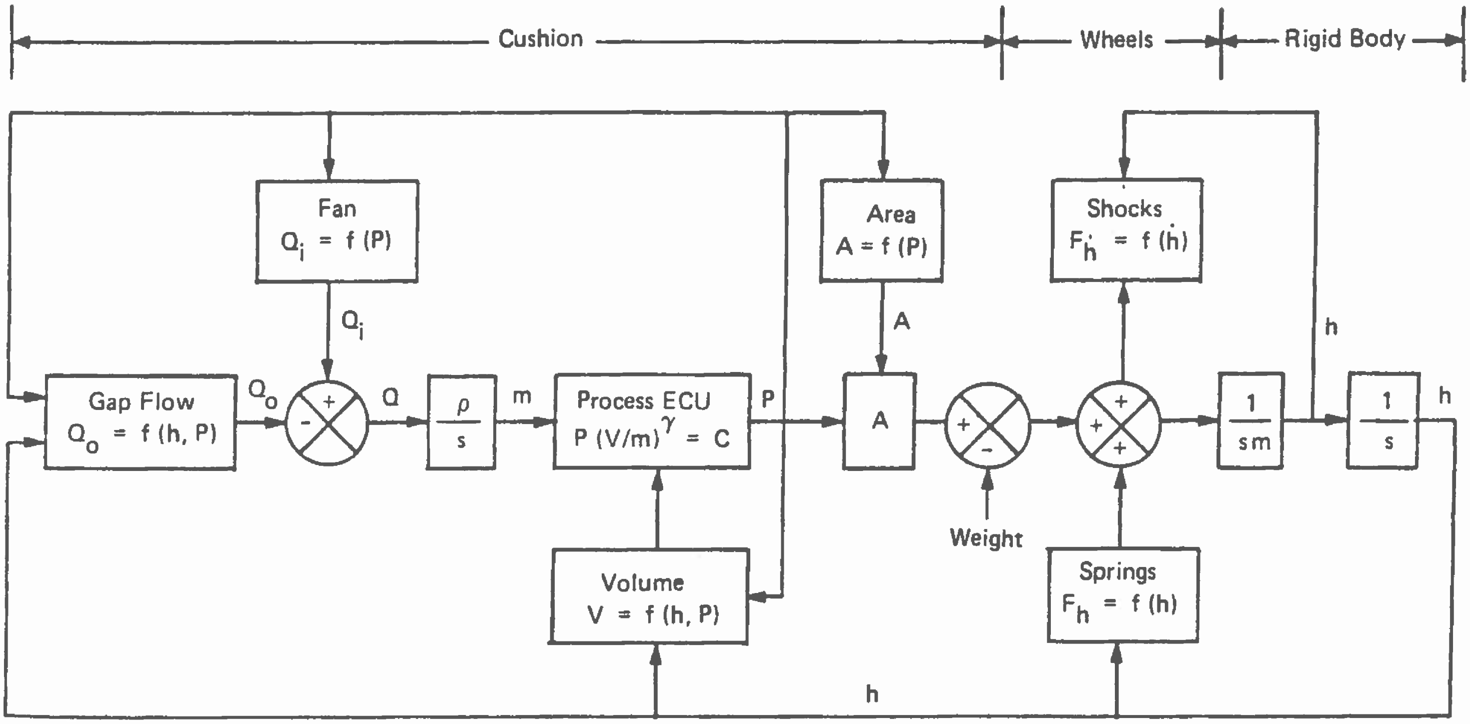


Figure 10.3 Hybrid Vehicle Model

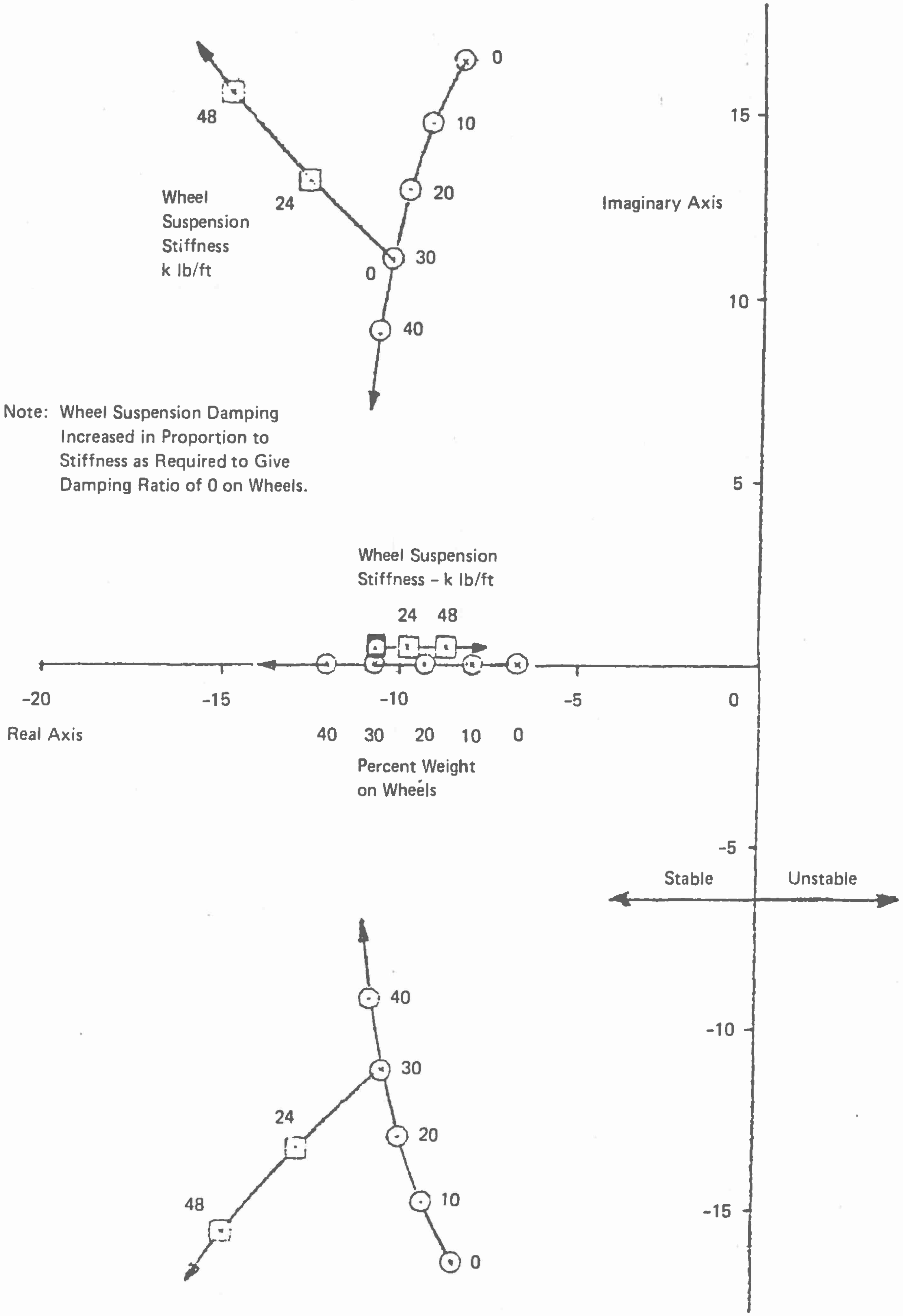


Figure 10.4 ACCRV Heave Stability in Hybrid Mode

hybrid mode can vary significantly depending on the wheel loading. At very low wheel loadings, it approaches the cushion only stiffness. At low wheel loadings, it is dominated by the wheel stiffness which is much higher than the cushion stiffness. The maximum cushion contribution in this case varies from 15% in pitch to 30% in roll. At the moderate wheel loadings of interest (30% weight on wheels), the high wheel stiffness results in excessive venting of the cushion with pitch and roll and loss of the cushion contribution unless the wheel positon is actively controlled to maintain a constant combined loading on all four wheels as the ACCRV is pitching and rolling. Thus, for the range of hybrid wheel loading operating of interest (=10 to 30% weight on wheels), it can be assumed that the static hybrid pitch and roll stiffness will be approximately equal to the wheel pitch and roll stiffness for the wheelborne mode. However, since the amount of weight that is carried on the wheels is much less than in the wheelborne mode, the maximum restoring moment at upward wheel lift off is much less than for the wheelborne mode. The maximum restoring moment is equal to the sum of the cushion and wheel load fractions times the respective maximum cushion and wheel restoring moments. The maximum pitch and roll moments are shown in Figure 10.5 as a function of weight on the wheels. As shown, roll stability in the hybrid mode does not provide sufficient margin for operation of the boom at full extension. Pitch stability provides adequate margin for full extension of the boom for 15% or greater weight on the wheels but would require shorter boom extensions to prevent tipping for less than 10% weight on the wheels.

10.3.2 Hybrid Control

Steering control in the hybrid mode is provided through front wheel steering. While not considered essential, additional steering control power is available by using the independent aft wheel brakes to brake the wheel on the ride in the direction of the desired turn, as is done on the water mode of operation.

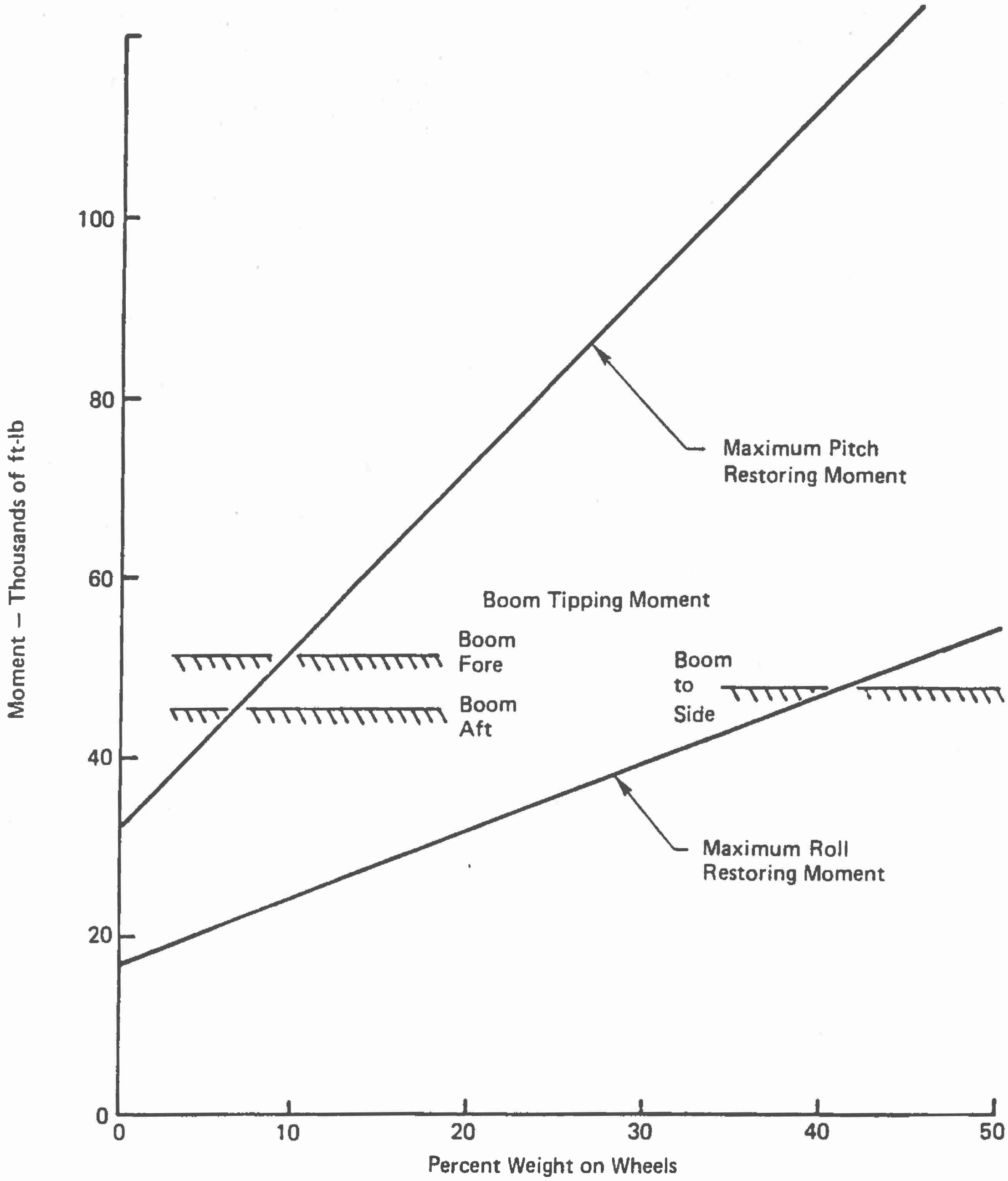


Figure 10.5 Static Attitude Stability - Hybrid Mode

11.0 DYNAMIC MODEL DESIGN, SCALING, AND TEST

This section of the Final Report describes the dynamic model task which includes a description of the scaling analysis, guidelines for the model design, and a preliminary checkout and demonstration plan for satisfying the contract statement of work.

11.1 Dynamic Model Scaling Analysis

11.1.1 Introduction

The following paragraphs define the model scale dimensions and scaled parameters for the ACCRV model. The scale factor required for each parameter is developed in Section 11.1.2. Scale size selection is discussed in Section 11.1.3, where it is concluded that a 1/5 scale model would be the optimum.

Model performance predictions are presented in Section 11.1.4. This section also contains the results of a dynamic analysis of both the full scale vehicle and a 1/5 scale model running over a backfilled crater. Comparison of the results confirms the validity of the scale factors developed in Section 11.1.2.

Section 11.1.5 is a summary of the 1/5 scale model stability predictions.

11.1.2 Derivation of Scaling Parameters

11.1.2.1 Introduction

The predominant forces acting on a vehicle which is traveling over a surface are inertia and gravitational forces. These are also the predominant forces acting on the water surface as the vehicle passes over it.

Writing the inertia force as the product of mass and acceleration;

$$\text{INERTIA FORCE} = m\,V\,dV/dx$$

where m = mass
V = velocity
x = distance

Thus, the inertia force has the units

$$(\text{mass}) \times (\text{velocity})^2/(\text{length})$$

Gravitational force is mg.

Therefore the ratio of inertia force to gravitational force is V^2/gl, which is sometimes defined as the Froude number. Some authors take the positive square root, $V/\sqrt{gl}$ and define that as the Froude number.

Froude scaling is used in this report, and the Froude number is defined as:

$$F_r = \frac{V}{\sqrt{gl}} \tag{1}$$

Denoting full scale by subscript FS, and model scale by subscript M, it is necessary to satisfy the relationship

$$\frac{V_M}{V_{FS}} = \left(\frac{\ell_M}{\ell_{FS}}\right)^{\frac{1}{2}} \tag{2}$$

Let $$\lambda = \frac{\text{Linear Dimension of Full Scale Craft}}{\text{Linear Dimension of the Model}} \tag{3}$$

i.e. $$\lambda = \frac{\ell_{FS}}{\ell_M} \tag{4}$$

11.1.2.2 Linear Dimensions

From Equation (4), all linear dimensions should be scaled by λ^{-1}.

11.1.2.3 Weights and Forces

Since weight is (specific weight) x (volume), all weights should be scaled by λ^{-3}. Weight is a force, so all forces scale by λ^{-3}.

11.1.2.4 Pressure

$$\text{PRESSURE} = \frac{\text{FORCE}}{\text{AREA}} \rightarrow \frac{\lambda^{-3}}{\lambda^{-2}} = \lambda^{-1}$$

Fan pressure, cushion pressure and tire pressure should all scale by λ^{-1}.

11.1.2.5 Linear Speed

It is seen from Equation (2) that linear speed scales as $\lambda^{-1/2}$.

11.1.2.6 Rotational Speed

$$\text{ROTATIONAL SPEED} = \frac{\text{TIP SPEED}}{\pi\ \text{DIA}} \rightarrow \frac{\lambda^{-.5}}{\lambda^{-1}} = \lambda^{.5}$$

Thus, model rotational speeds should be <u>increased</u> by the factor $\lambda^{1/2}$.

11.1.2.7 Air Flow Rate

$$\text{AIR FLOW RATE} = (\text{AREA}) \times (\text{VELOCITY}) > \lambda^{-2} \cdot \lambda^{-1/2} = \lambda^{-2.5}$$

11.1.2.8 Thrust

Thrust, being a force, should scale as λ^{-3}.

11.1.2.9 Power

$$\text{POWER} = \frac{\text{(THRUST) x (VELOCITY)}}{\text{(EFFICIENCY)}} \rightarrow \lambda^{-3} \cdot \lambda^{-.5} = \lambda^{3.5}$$

The lower Reynolds numbers associated with the model will tend to reduce efficiency, but this effect has been shown to be small (less than 5%) for $1.0 < \lambda < 5.5$ in the case of centrifugal fans, Reference (10).

11.1.2.10 Thrust Loading, Slip Factor and Propulsive Efficiency

Thrust loading is defined as:

$$C_T = T/(\frac{1}{2} \rho A_B V_o^2) \qquad (5)$$

where
T = Thrust
ρ = Density
A_B = Propulsor area
V_o = Free stream velocity

$$\text{Therefore, } \frac{C_{T.M}}{C_{T.FS}} = \frac{T_M}{T_{FS}} \cdot \frac{A_{FS}}{A_M} \quad \frac{V_{FS}}{V_M}^{\;2}$$

$$= \lambda^{-3} \cdot \frac{1}{\lambda^{-2}} \cdot \quad \frac{1}{\lambda^{-.5}}^{\;2}$$

$$= 1.$$

Thus, Froude scaling satisfies the requirement of equal thrust loadings on the model and full scale craft.

The slip factor is defined as

$$S = (V_B - V_o)/V_B \qquad (6)$$

where:
V_B = Track speed relative to the craft
V_o = Craft speed relative to the water.

$$\text{Therefore, } \frac{SM}{S_{FS}} = \frac{\lambda^{-.5}}{\lambda^{-.5}} = 1$$

Since propulsive efficiency is a function of thrust loading or of slip only, it is seen that Froude scaling ensures that the model and the full scale craft will have the same thrust loadings, slip factors and propulsive efficiencies.

11.1.2.11 Time

It is important to note that for dynamic similitude time must also be scaled.

$$\text{TIME} = \frac{\text{LENGTH}}{\text{SPEED}} \rightarrow \frac{\lambda^{-1}}{\lambda^{-.5}} = \lambda^{-.5}$$

11.1.2.12 Acceleration (G)

$$\text{ACCELERATION} = \frac{\text{FORCE}}{\text{MASS}} \rightarrow \frac{\lambda^{-3}}{\lambda^{-3}} = 1$$

Thus acceleration, model and full scale, should be equal.

11.1.2.13 Pitch Acceleration (Deg./sec^2)

$$\text{PITCH ACCELERATION} = \frac{\text{DEGREES}}{(\text{SECONDS})^2} \rightarrow \frac{1}{(\lambda^{-.5})^2} = \lambda$$

Therefore, model pitch accelerations will be λ times larger than full scale craft pitch accelerations in terms od DEG/SEC^2.

11.1.2.14 Spring Constants

$$\text{SPRING CONSTANT} = \frac{\text{FORCE}}{\text{LENGTH}} \rightarrow \frac{\lambda^{-3}}{\lambda^{-1}} = \lambda^{-2}$$

11.1.2.15 Damping Coefficients

$$\text{DAMPING COEFF} = \frac{\text{FORCE}}{\text{VELOCITY}} \rightarrow \frac{\lambda^{-3}}{\lambda^{-.5}} = \lambda^{-2.5}$$

It is to be noted that the spring constant and damping coefficient do not scale by the same factor. The ratio of the damping coefficient to the spring constant has the unit of time.

$$\frac{\text{DAMPING COEFF}}{\text{SPRING CONST}} \rightarrow \frac{\lambda^{-2.5}}{\lambda^{-2}} = \lambda^{-.5}$$

which is the correct scaling factor for time.

11.1.2.16 Heave Stability Index

If the index is greater than 1.0 then the craft will be stable in heave.

$$HSI = \frac{\gamma \bar{P}_c h_g}{h_c Q} \left| \frac{Q}{2P_c} - \frac{\partial Q}{\partial P}_F \right| \qquad (7)$$

where
γ = process exponent
P_c = absolute cushion pressure
P_c = gage cushion pressure
Q = cushion flow rate
h_c = cushion depth
h_g = gap height under cushion
$\frac{\partial Q}{\partial P}_F$ = slope of the fan curve.

Since the scaling factor for air flow rate is $\lambda^{-2.5}$, and for pressure it is λ^{-1}, then the model fan curve slope should be $\lambda^{-2.5}/\lambda^{-1}$, i.e., $\lambda^{-1.5}$ times that of the full scale fan. This will be satisfied if the fans exhibit the same non-dimensional ψ - ϕ plots, where

$$\psi = \frac{P}{\rho U_2^2} \rightarrow \frac{\lambda^{-1}}{(\lambda^{-.5})^2} = 1 \qquad (8)$$

$$\phi = \frac{Q}{\pi D_2 B_2 U_2} \rightarrow \frac{\lambda^{-2.5}}{\lambda^{-1}\ \lambda^{-1}\ \lambda^{-.5}} = 1 \qquad (9)$$

and where
P = fan pressure
U_2 = impeller tip speed
Q = volume flow rate
D_2 = impeller outside dimaeter
B_2 = blade span at D_2
ρ = air density
ψ = non-dimensionalized pressure
ϕ = non-dimensionalized flow

It is seen from Equations (8) and (9) that $\frac{\partial Q}{\partial P}_F = k \frac{\partial \phi}{\partial \psi}$ at constant rpm; k = constant.

Equations (7) shows that:

$$\frac{HSI_M}{HSI_{FS}} = 1, \text{ is non-dimensional}$$

and if the fan curve slope is modeled correctly, HSI_M will be equal to HSI_{FS}. This indicates that if the model is stable in heave, then the full scale craft will also be stable in heave. However, since the heave index depends on a pressure ratio using the scaled cushion pressure and atmospheric pressure, and since atmospheric pressure is not scaled in the model, it cannot be concluded that if the model is stable in heave, the full size craft will also be stable. In practice the full size craft is generally not as stable in heave, if the model is stable in heave.

11.1.2.17 Pitch and Roll Moments

Moments, being the product of a force and a distance, have the scale factor $\lambda^{-3} \cdot \lambda^{-1} = \lambda^{-4}$.

11.1.2.18 Natural Frequency

Since the frequency is measured in cycles per second the correct scale is $1/\lambda^{-1/2} = \lambda^{1/2}$, showing that a 1/5 scale model will oscillate at a rate that is 2.24 times that of the full scale vehicle.

11.1.3.0 Scale Size Selection

Figures 11-1 and 11-2 list various hardare and performance parameters for the full scale craft and for models scaled to 1/6, 1/5, and 1/4.

The upper and lower limits on model size are dictated by model weight as defined in Reference 11 where it is stated that it must be at least 150 lbs. but no greater than 1000 lbs. Therefore, $\lambda_{min} = (30{,}000/1000)^{1/3} = 3.1$, showing that a 1/3 scale model would be too heavy. Also, $\lambda_{max} = (30{,}000/150)^{1/3} = 5.8$, showing that a 1/6 scale model would be too light.

Since there appears to be no advantage in selecting a 1/4 scale model over a 1/5 scale, a 1/5 scale was selected on the basis of convenience in handling and transporting.

11.1.4.0 Scaled Performance

The scaled weight of the basic vehicle is 240 lbs., which represents a full scale weight of 30,000 lbs. Model performance predictions have been made for this weight (240 lbs.), and for weights of 200 lbs. and 280 lbs. which represent full scale weights of 25,000 lbs. and 35,000 lbs., respectively.

11.1.4.1 Over Water

11.1.4.1.1. Thrust and Drag

The predicted over-water drag curves for seastate zero and for 2.4 in. waves (representing 1.0 ft. waves full scale) are plotted in Figure 11-3 for the 1/5 scale model at weights of 200 lbs., 240 lbs., and 280 lbs. The predicted model paddle track thrust curve is also plotted on the same figure. The intersections of the thrust and drag curves indicate the following maximum over-water speeds.

MODEL WEIGHT (lb.)	MODEL SPEED (MPH) SEASTATE ZERO	MODEL SPEED (MPH) 2.4 IN. WAVES
200	4.55	4.5
240	4.4	4.35
280	4.35	4.3

PARAMETER	UNITS	FULL SIZE	SCALING INDEX	MODEL SCALE		
				1/6	1/5	1/4
LENGTH	IN.	407	-1	67.8	81.4	101.8
WIDTH	IN.	110	-1	18.3	22.0	27.5
HEIGHT	IN.	105	-1	17.5	21.0	26.3
WEIGHT	LB.	30,000	-3	138.9	240	468.8
SPEED ON LAND	MPH	65	-½	26.5	29.1	32.5
SPEED OVER WATER	MPH	10	-½	3.3	4,4	4.0
OBSTACLE HEIGHT	IN.	12	-1	2.0	2.4	3.0

Figure 11-1. Craft and Performance Scaling

PARAMETER	UNITS	FULL SIZE	SCALING INDEX	MODEL SCALE		
				1/6	1/5	1/4
CUSHION PRESSURE	PSF	71	-1	11.8	14.2	17.8
AIR FLOW RATE	CFS	900	-2.5	10.2	16.1	28.1
FAN SPEED	RPM	3910 (MAX.)	+½	9578	8743	7820
FAN HORSEPOWER	HP	250 350 (MAX.)	-3.5 -3.5	0.5 0.7	0.9 1.3	2.0 2.7
PAD. TRK. THRUST	LB.	2200	-3	10.2	17.6	34.4
PAD. TRK. TIP SPEED	FPS	42.8	-½	17.5	19.1	21.4
PAD. TRK. HORSEPOWER	HP	280	-3.5	0.5	1.0	2.2
TOTAL HORSEPOWER	HP	700	-3.5	1.3	2.5	5.5
STRUT STIFFNESS	LB/IN		-2.0			
HYBRID		380		10.6	15.2	23.8
WHEELED		760		21.1	30.4	47.5
STRUT DAMPING COEFFICIENT	LB.SEC/FT		-2.5			
HYBRID		922		10.5	16.5	28.8
WHEELED		1305		14.8	23.3	40.8

Figure 11-2. Lift and Propulsion System Scaling

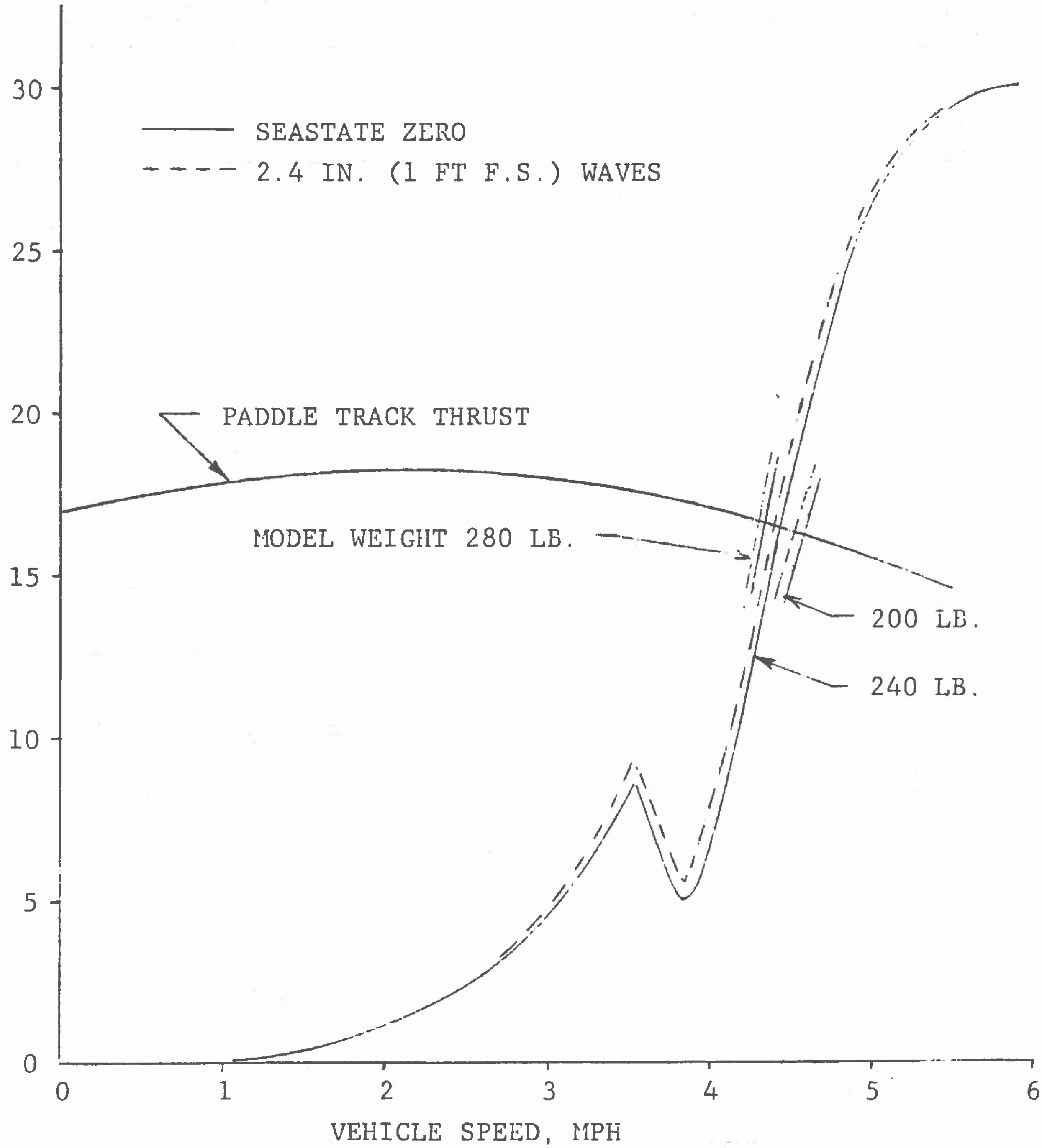


Figure 11-3. ACCRV 1/5th Scale Model Over Water Thrust and Drag

These data demonstrate the small effect that the vehicle model weight has on over-water speed. The reason for this is the combination of a very flat thrust curve and very steep drag curves in the region of intersection of the lines.

The accuracies indicated by the above table are not expected to be realized in practice. Rather, they should be regarded as an indication that the model speed over water will be 4 to 4-1/2 mph.

11.1.4.1.2 Static Pitch Stability

Static pitch stability curves are presented in Figure 11-4 for the three model weights: 200 lbs., 240 lbs. and 280 lbs. These curves were scaled from data given in reference 3 for the full scale craft by applying the scale factor λ^{-4}, i.e., 1/625 for the 1/5 scale model. Figure 11-4 shows that for small angles an average pitch stiffness of 5.7 ft-lb/deg. may be assumed.

11.1.4.1.3 Static Roll Stability

Figure 11-5 is a plot of restoring roll moment versus roll attitude for the loaded and empty model weights. The data for these curves were taken from Reference 12 and converted to model scale by applying the scale factor λ^{-4} (1/625 for the 1/5 scale model). For small roll angles the average roll stiffness is approximately 2.5 ft-lb/deg.

11.1.4.1.4 Heave Stability

The heave stability index quoted in Reference 12 for the full scale craft is 3.9 at 100% fan rpm and 5.3 at 70% fan rpm. It was shown in Section 11.1.2.16 that, if the fan curve is modeled correctly, model and full scale heave stability indices will be identical.

11.1.4.2 Over Land - Wheelborne

11.1.4.2.1 Heave Frequency

The combined model tire/suspension stiffness of 30.4 lb/in. per wheel results in undamped natural heave frequencies of 2.44, 2.23, and 2.06 hertz for model weights of 200, 240, and 280 lbs., respectively.

11.1.4.2.2 Damping Ratio

The critical damping coefficients for the three model weights are 190.5, 208.7, and 225.4 lb sec/ft. Since the 1/5 scale model damping coefficient for 4 struts is 93.2 lb sec/ft., the damping ratios are 0.49, 0.45, and 0.41 for the 200, 240, and 280 lb. models, respectively.

11.1.4.2.3 Pitch Stiffness

The horizontal distance from the front wheel of the full scale vehicle tot he center of gravity is 8.67 ft., and from the center of gravity to the rear wheel is 8.50 feet. With a strut stiffness of 9120 lb/ft., the resulting vehicle pitch stiffness is 46,928 ft lb/degree.

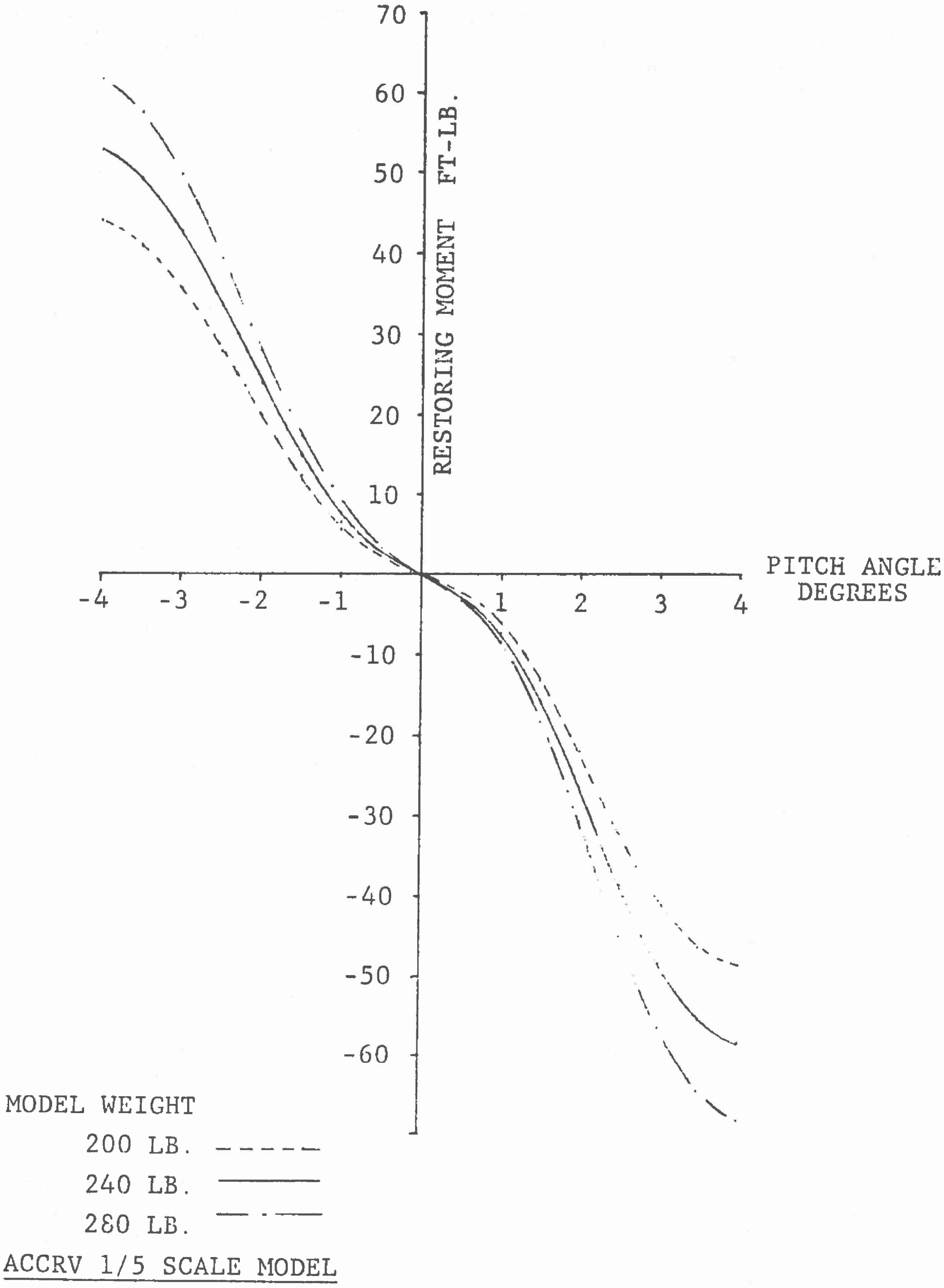


Figure 11-4. Static Pitch Stability - Over Water Cushionborne Mode

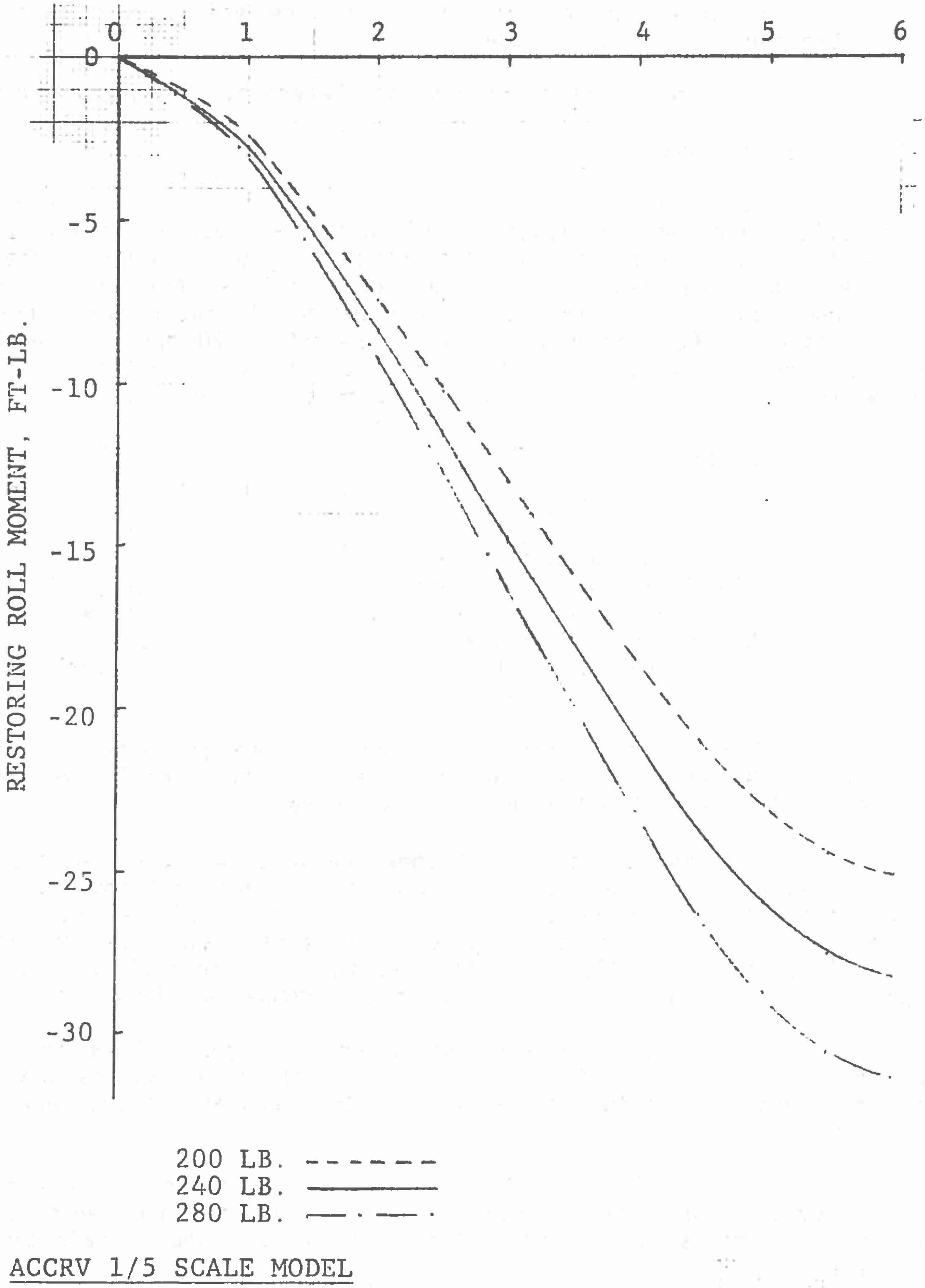


Figure 11-5. Static Roll Stability - Over Water Cushionborne Mode

As shown in Section 11.1.2.17, the model scale factor is λ^{-4}, or 1/625 for the 1/5 scale model.

The model pitch stiffness is, therefore, 75.1 ft lb/degree.

11.1.4.2.4 Dynamic Analysis

As a check on the validity of the scale factors developed in Section 11.1.2, a dynamic analysis of one particular case was conducted for both the full scale and 1/5 scale vehicles using BAT's VEHDYN code. A back-filled crater was selected for the ground profile, and the full scale vehicle speed was 20 mph. The full scale and model crater dimensions are shown in Figure 11-6. The model speed representing 20 mph full scale is 8.94 mph. The following table gives the factors by which the full scale values were divided to compute the 1/5 scale model parameters.

Parameter	Divide By
All linear dimensions	5
Mass or weight	125
Linear spring constants	25
Rotational spring constant	625
Damping coefficients	55.9
Mass moment of inertia	3125
Linear velocity	2.236
Tire pressure	5

The results of the dynamic analysis are presented in Figures 11-7, 11-8, 11-9, and 11-10 for the full scale vehicle, and in Figures 11-7A, 11-8A, 11-9A and 11-10A for the 1/5 scale model.

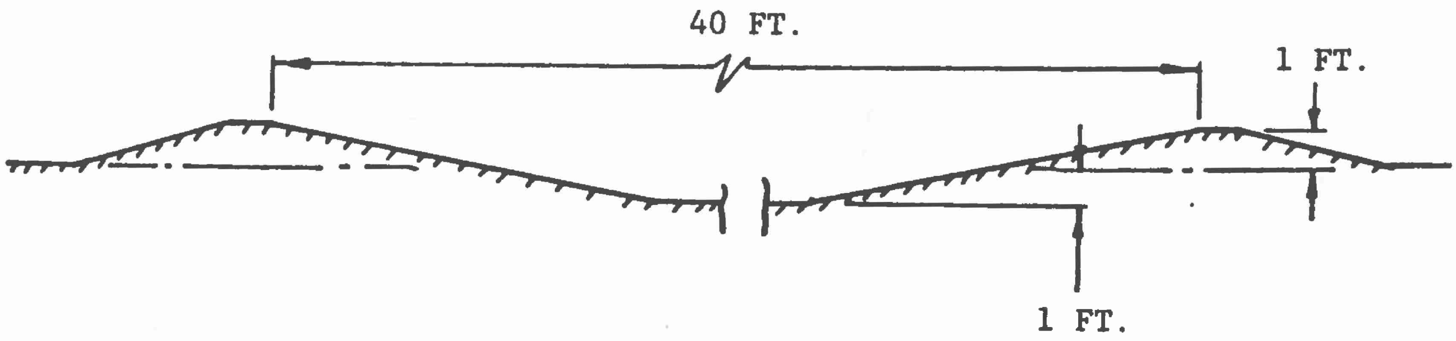
Figures 11-7 and 11-7A show the vertical accelerations versus time. Referring to Section 11.1.2.12, it is seen that the amplitudes of these plots should be identical. Direct comparison of the graphs shows this to be correct. The model (Figure 11-7A) time scale, however, should be 1/ 5 (Section 11.1.2.11) or 0.447 times that for the full scale vehicle (Figure 7). This is also seen to be correct by comparing the plots.

The pitch accelerations given in Figures 11-8 and 11-8A should be in the ratio λ (Secton 2.13), i.e., the model values should be five times those of the full scale values. Measurements of the peaks confirms this.

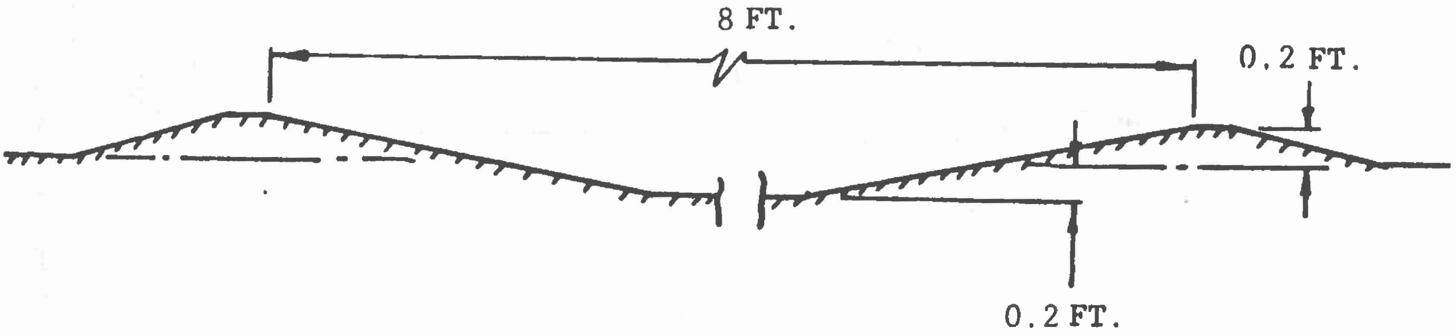
Figures 11-9 and 11-9A give the suspension system compression, in feet, versus time for the full scale and 1/5 scale vehicles, respectively. Compression, being a linear distance, should scale by λ^{-1}, i.e., by 1/5.

Comparison of Figures 11-9 and 11-9A shows that the compression strokes do scale in that ratio.

Forward and aft ground clearances are plotted versus distance in Figures 11-10 (full scale) and 11-10A (1/5 scale). It is seen



FULL SCALE PROFILE



1/5 SCALE PROFILE

Figure 11-6. Full Scale and Model Scale Ground Profiles for Dynamic Analyses

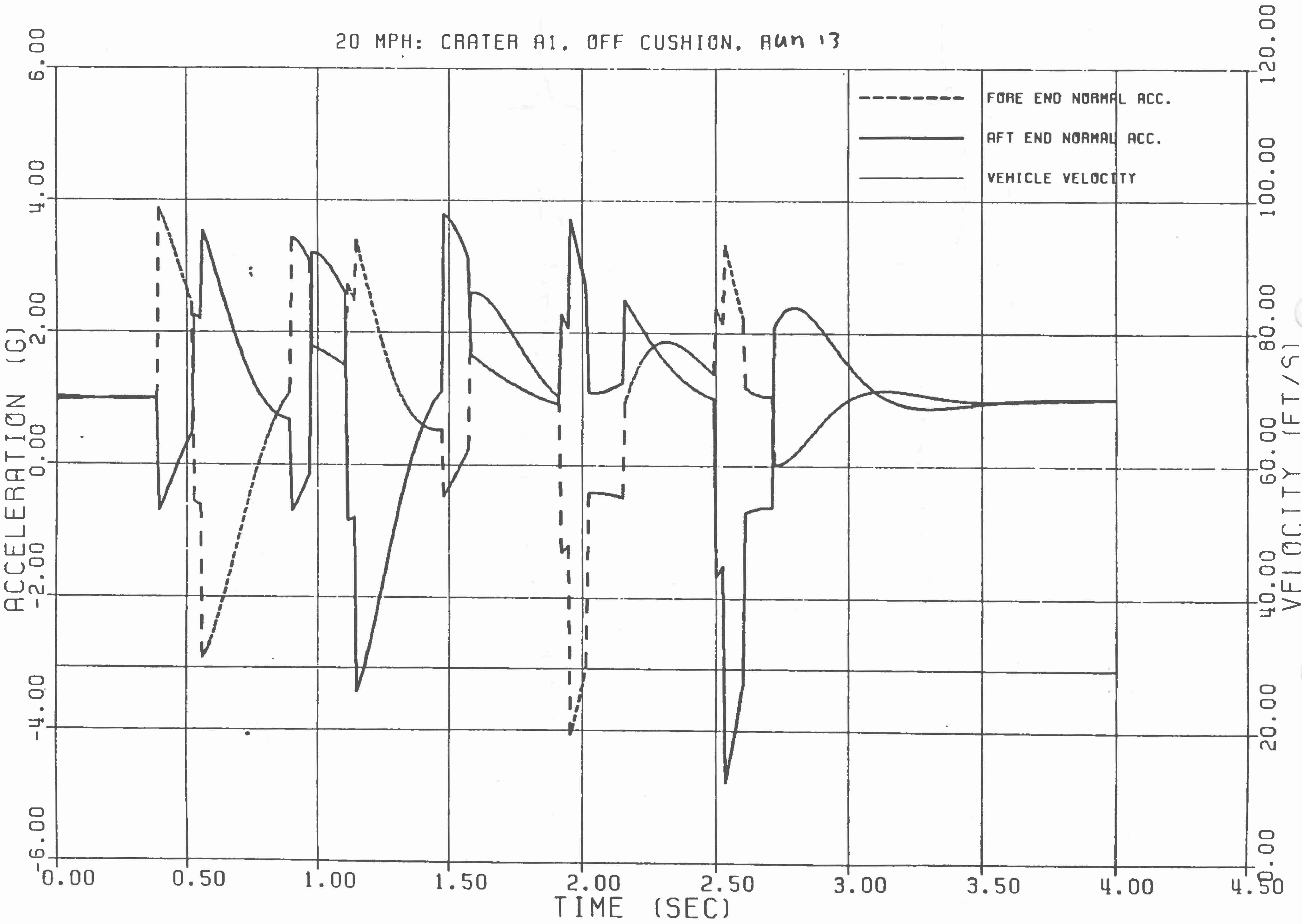


Figure 11-7. ACCRV Vehicle Dynamic Analyses
Normal Acceleration versus Time

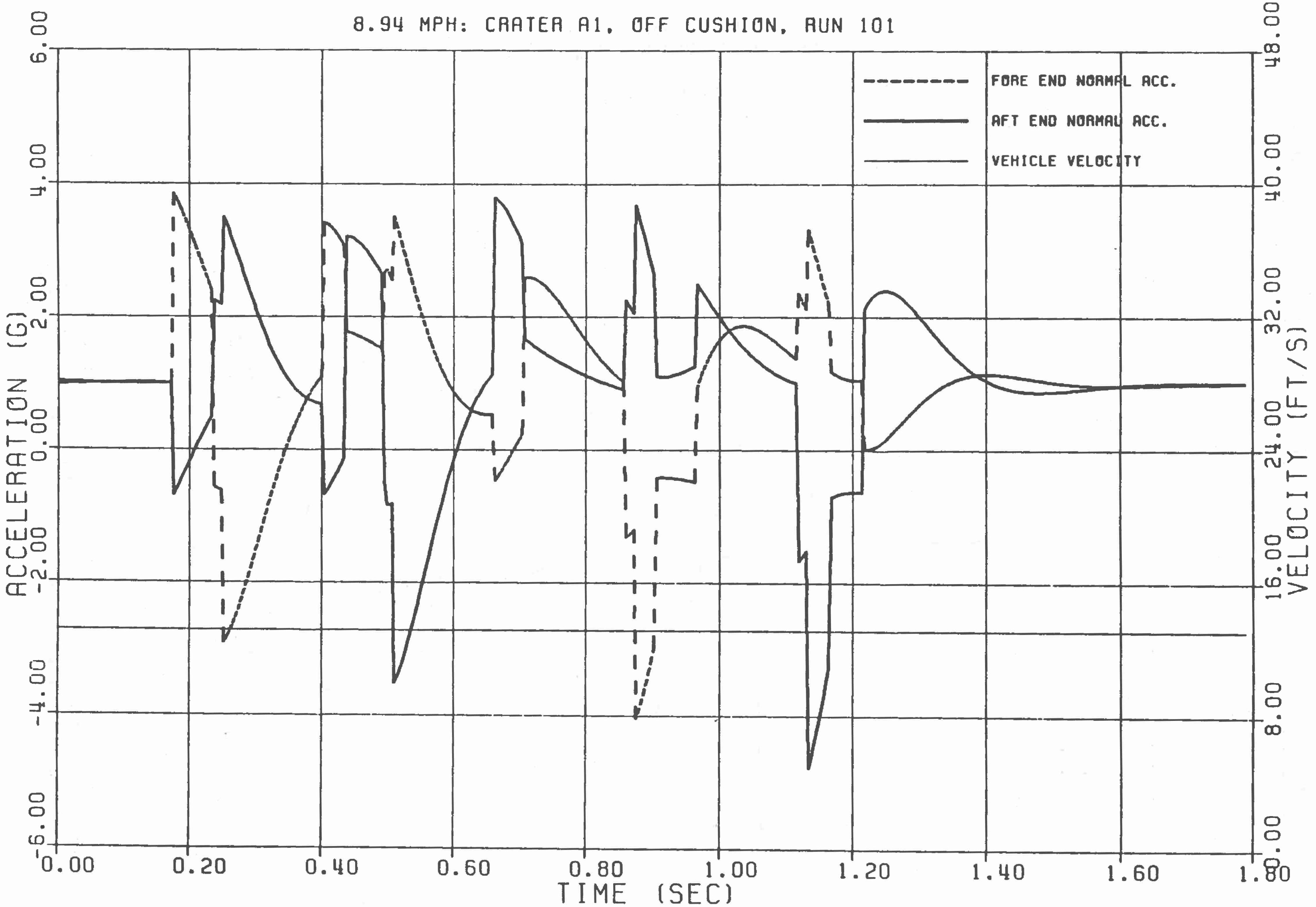


Figure 11-7A. ACCRV 1/5th Scale Vehicle Dynamic Analyses
Normal Acceleration versus Time

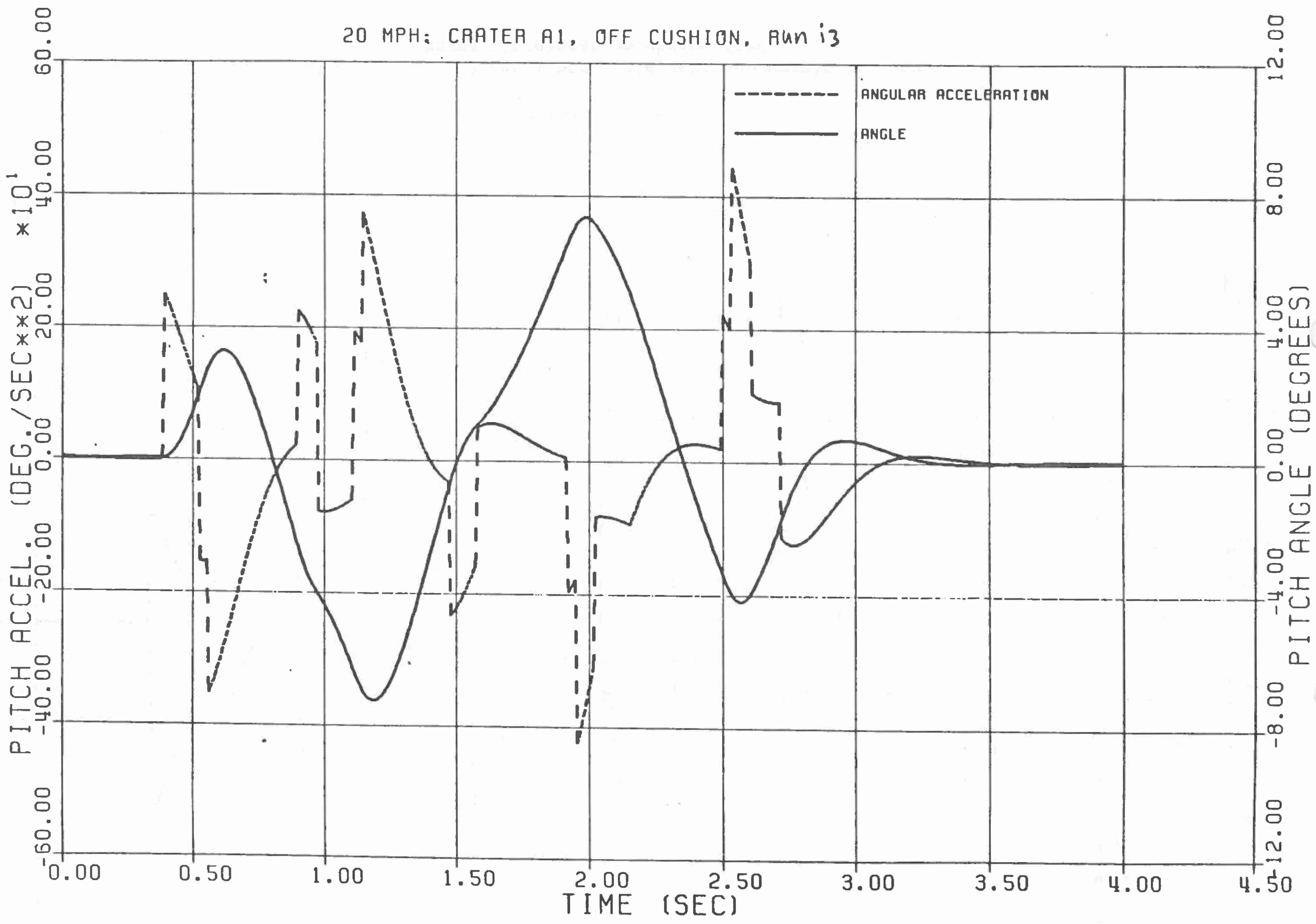


Figure 11-8. ACCRV Vehicle Dynamic Analyses
Pitch Angle and Acceleration

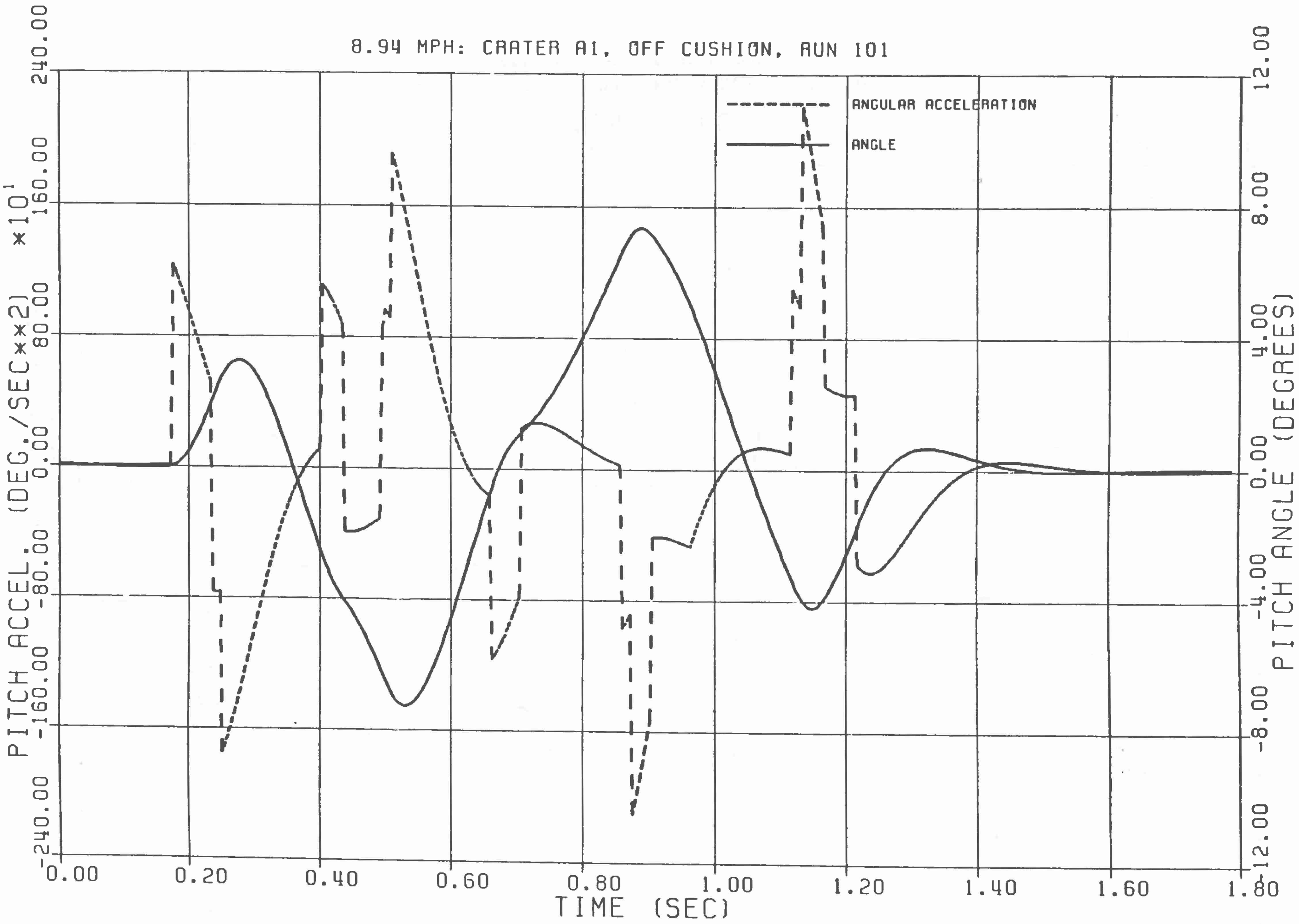


Figure 11-8A. ACCRV 1/5th Scale Vehicle Dynamic Analyses
Pitch Angle and Acceleration

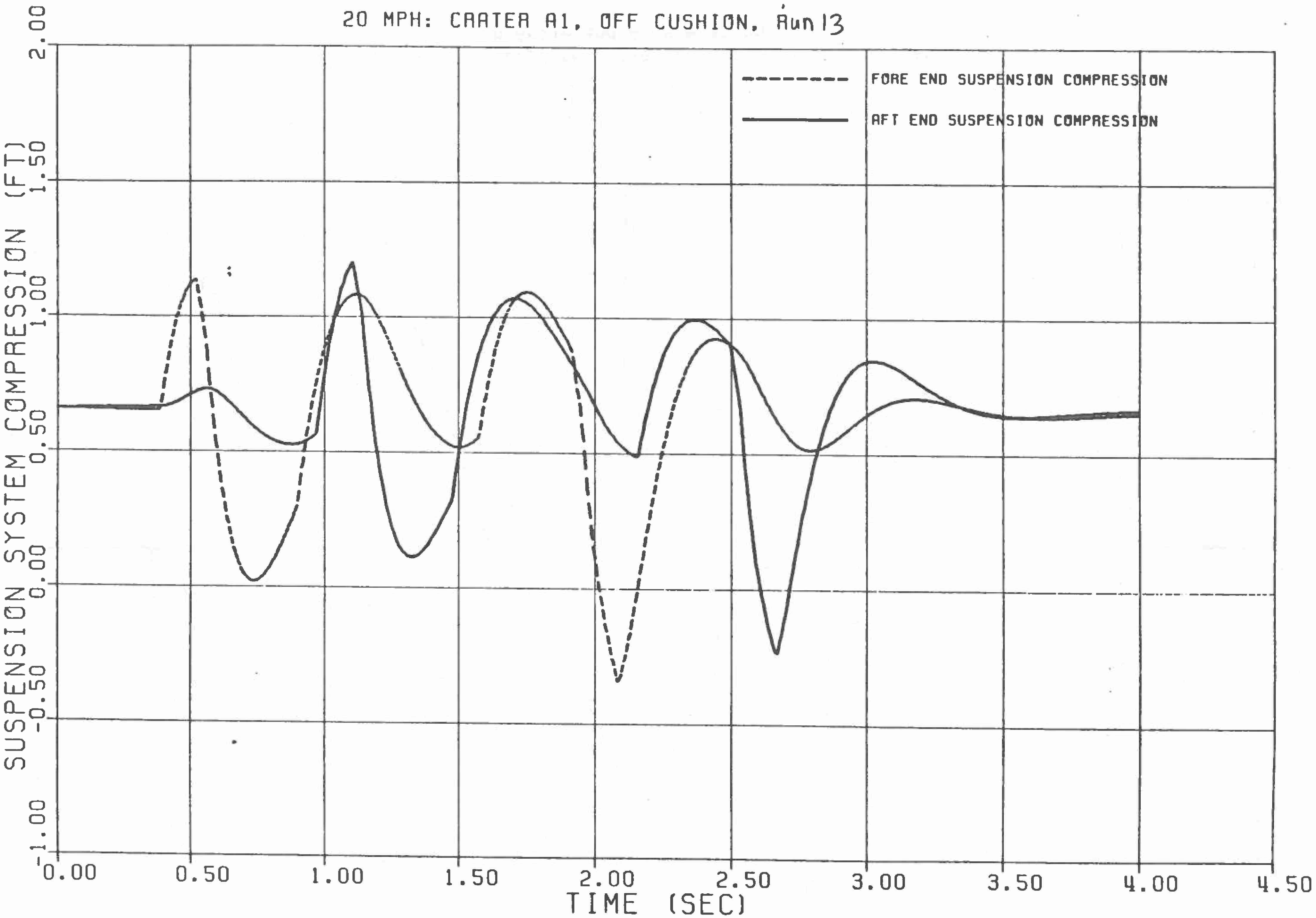


Figure 11-9. ACCRV Vehicle Dynamic Analyses
Suspension Compression versus Time

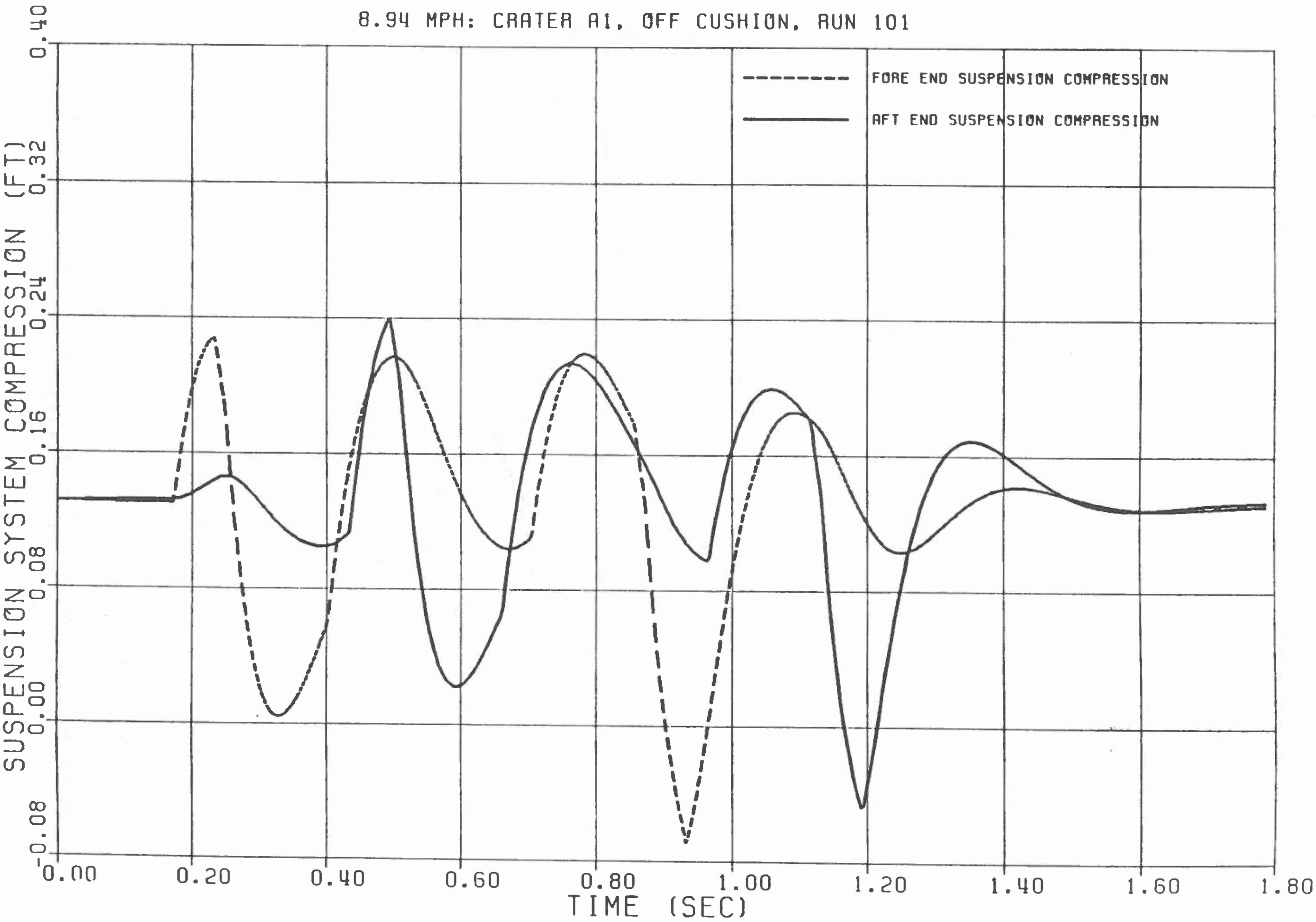


Figure 11-9A. ACCRV 1/5th Scale Vehicle Dynamic Analyses
Suspension Compression versus Time

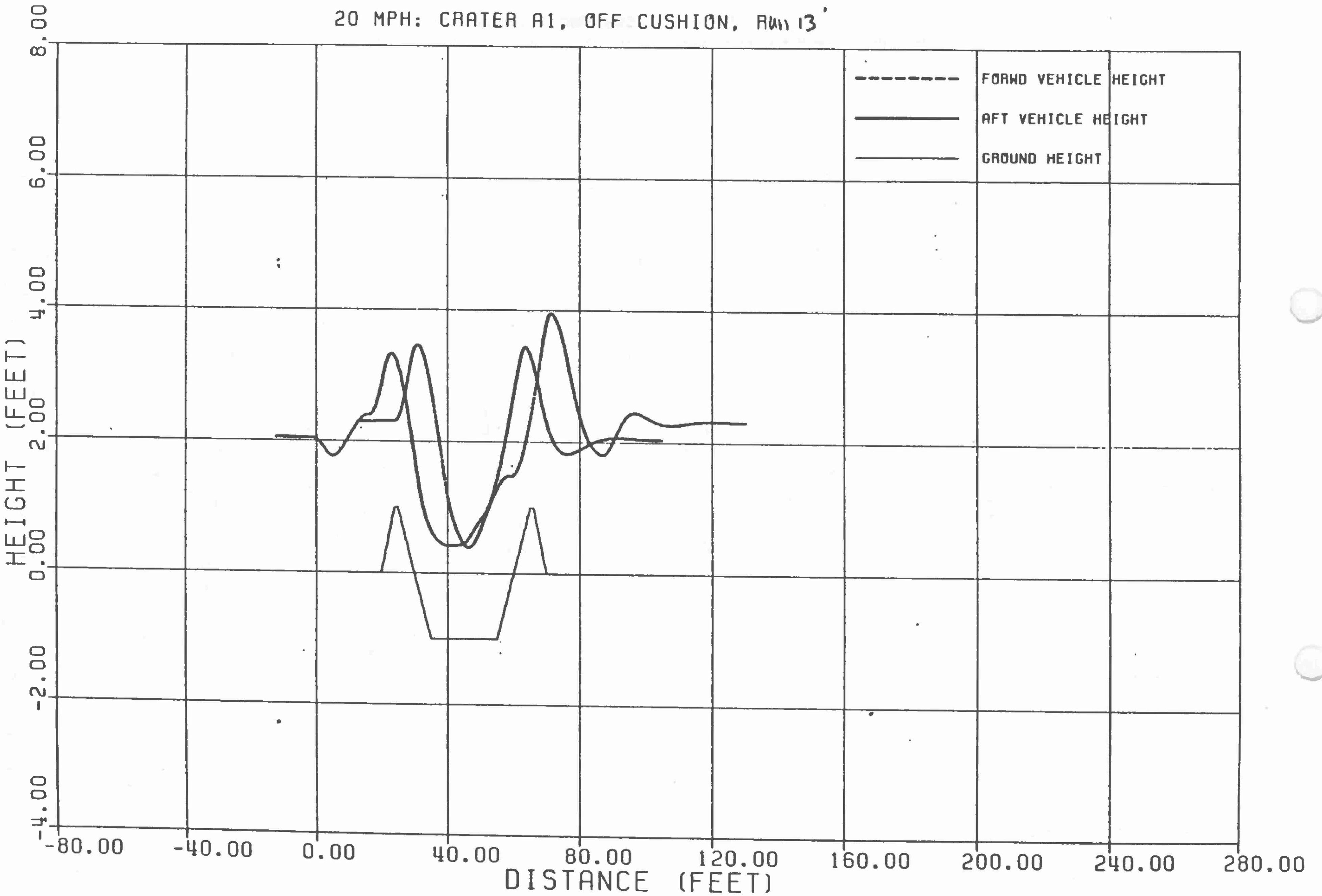


Figure 11-10. ACCRV Vehicle Dynamic Analyses
Vehicle Fwd and Aft Ground Clearance

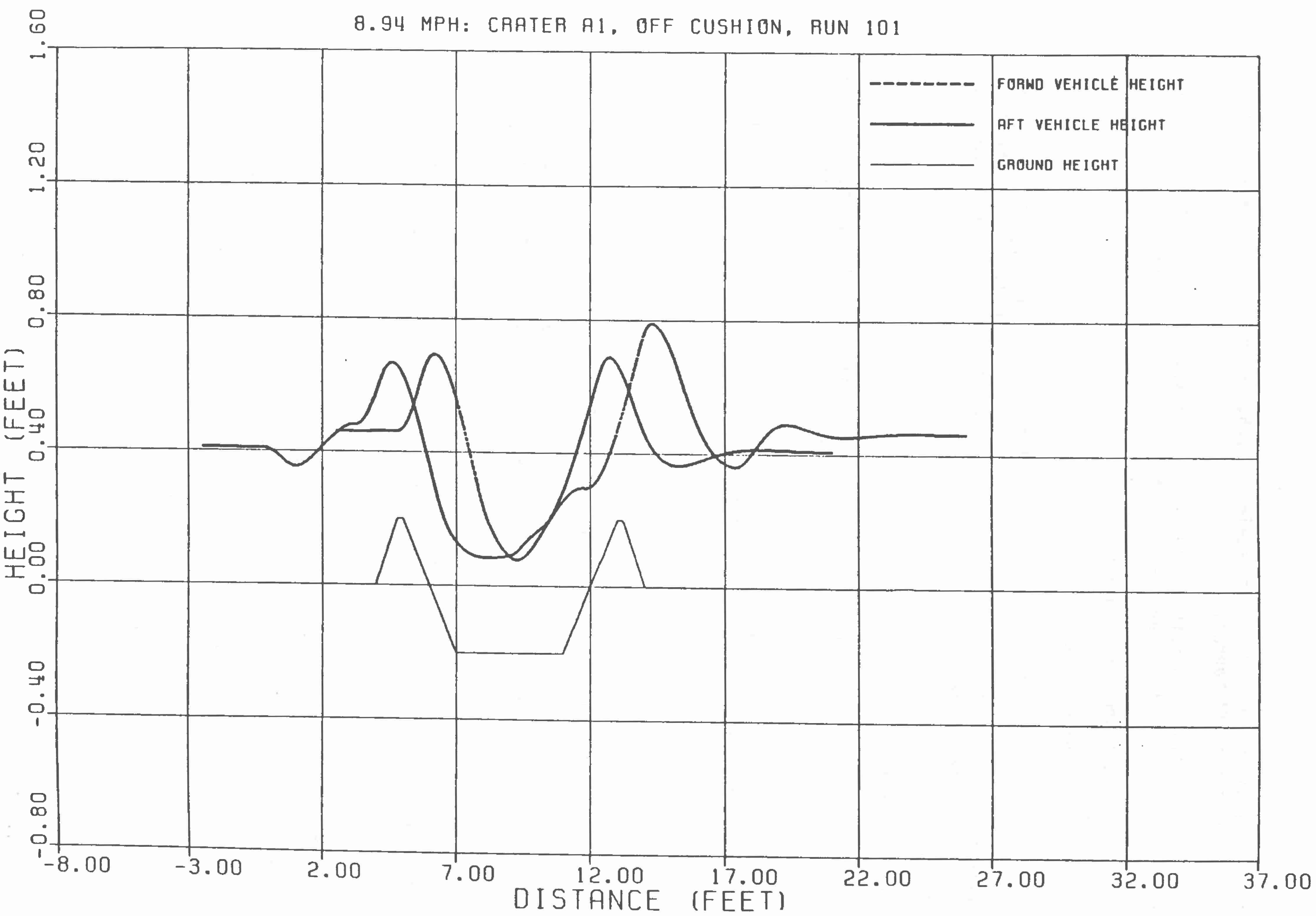


Figure 11-10A. ACCRV 1/5th Scale Vehicle Dynamic Analyses
Vehicle Fwd and Aft Ground Clearance

that both height and distance scale by 1/5, which is the correct scale factor for linear distances.

This dynamic analysis demonstrates conclusively that the scaled values which have been assigned to the model are correct.

11.1.4.3 Over Land - Hybrid Mode

11.1.4.3.1 Pitch Stiffness

Under hybrid conditions, the model strut stiffness is reduced to 15.2 lb/in. The cushion pressure is also reduced from the "on-cushion" value of 14.2 psf to 11.0 psf. Combination of the air cushion and the wheel struts result in a hybrid mode pitch stiffness of 41.5 ft lb/degree.

11.1.5.0 Summary

From considerations of the maximum and minimum permissible model weights, and from the points of view of handling and transportation, a 1/5 scale has been selected for the model.

The following tables (Table 11-1 and Table 11-2) summarize the full scale and model scale parameters.

Table 11-1. Performance as a Function of Weight

PARAMETER	UNITS	MODEL WEIGHT (LB) 200	240	280
Over Water				
Small Angle Static Pitch Stiffness	ft lb/deg.	4.5	5.7	6.5
Small Angle Static Roll Stiffness	ft lb/deg.	2.1	2.5	2.7
Over Land - Wheelborne				
Undamped Natural Heave Frequency	hertz	2.44	2.23	2.06
Critical Damping Coefficients	lb sec/ft	190.5	208.7	225.4
Damping Ratio	ND	0.49	0.45	0.41
Pitch Stiffness	ft lb/deg	75.1	75.1	75.1
Over Land - Hybrid Mode				
Pitch Stiffness	ft lb/deg	41.5	41.5	41.5

Table 11-2. Basic Loaded Vehicle

PARAMETER	UNITS	FULL SCALE	MODEL SCALE
Length	in.	407	81.4
Width	in.	110	22.0
Height	in.	105	21.0
Wheel O.D.	in.	52.5	10.5
Track Width	in.	20	4.0
Track Cleat Height	in.	3	0.6
Wheel Base	in.	207	41.4
Gross Weight	lbs.	30,000	240
Moments of Inertia	lb.in^2		
Ixx		4.40×10^7	1.41×10^4
Iyy		1.74×10^8	5.57×10^4
Izz		1.66×10^8	5.31×10^4
CG Position	in.		
X		182.5	36.5
Y		0.6	0.1
Z		30.6	6.1
Cushion Pressure	psf		
On Cushion		71	14.2
Hybrid Mode		55	11.0
Tire Pressure	psi	40	8.0
Air Flow Rate	cfs	900	16.1
Fan Horsepower	HP	250 350 (max.)	0.9 1.3 (max.)
Track Thrust	lb	2200	17.6
Track Tip Speed	fps	42.8	19.1
Track Horsepower	HP	280	1.0
Total Horsepower	HP	700	2.5
Speed on Land	MPH	65	29.1
Speed Over Water	MPH	10	4.4
Obstacle Height	in.	12	2.4
Strut Stiffness	lb/in		
Hybrid Mode		380	15.2
Wheeled Mode		760	30.4
Strut Damping Coeff.	lb-sec/ft		
Hybrid Mode		922	16.5
Wheeled Mode		1305	23.3

NOTE: The origin of the coordinate system is located at the vehicle front center, in plane with the lowest horizontal surface.

11.2 Design and Fabrication Guidelines for the Model Maker

11.2.1 ACCRV Model Body

The ACCRV model body will be of welded 3/4 inch square aluminum tubing construction with sheet metal skin pop-riveted onto it. The body will approximately simulate the ACCRV profile without any external detailing such as windows, ladder, railing, etc. The body tubing construction will provide the mounting for all internal drives and suspension. The sheet metal skin on the bottom side will be sealed to reduce water leakage into the body.

11.2.2 ACCRV Drive System for the Model

The wheel/track system will be designed and built similar to the full-size ACCRV. A 1-HP AC motor and drive belt will drive the main shaft along the body centerline. A forward and aft differential will connect this shaft to axles. The forward wheels will be geared to allow $\pm 30^{\circ}$ rotation for sterring. A rotation lock will allow positioning the wheels for the 35-foot diameter track and straight ahead testing.

A mid-body shaft will drive a drive belt inside the transfer case, which in turn drives the rear wheels and tracks. Manually operated brakes on the mid-body shaft will allow differential speeds between the rear wheels. The two tracks will always be turning with the rear wheels.

11.2.3 ACCRV Track Design for the Model

The track design will incorporate a 4.5 inch wide by 47 inch long belt onto which cleats are attached. Sprockets and rollers attached onto a beam inside the track will provide the required shape and suspension. The rear axle will not have independent suspension between left and right wheels. Height adjustment on the rear axle will be accomplished by a lead screw device on the upper end of the shocks. Shocks will incorporate an adjustment for stiffness.

11.2.4 ACCRV Air Bag System for the Model

An AC motor will drive the single Bell supplied centrifugal fan located on the model centerline at the front of the model. A fold-down air bag assembly will be designed to duplicate the full size air bag to the degree determined by Bell. A plywood top surface will hinge from the vehicle body. Rubber fabric will be cut and bonded into the air bag shape by the model maker. Coordination with the Bell representative will be required to correctly duplicate the air bag flow and suspension characteristics.

11.2.5 ACCRV Model Drawing List

A list of model drawings, revisions, and drawing dates are shown in Table 11-3.

Table 11-3. ACCRV Model Drawing List

DR-1	Track Support Assembly	Revision A	8/22/86
DR-2	Suspension		8/22/86
DR-3	Rear Axle Assembly	Sheet 1 of 2	10/10/86
		Sheet 2 of 2	10/18/86
DR-4	Transaxle Assembly	Sheet 1 of 2	9/26/86
		Sheet 2 of 2	10/3/86
DR-5	Track Support Assembly	Sheet 1 of 2	10/14/86
		Sheet 2 of 2	10/14/86
DR-6	Differential	Sheet 1 of 3	9/24/86
		Sheet 2 of 3	9/12/86
		Sheet 3 of 3	9/12/86
DR-7	Track Layout	Revision C	10/6/86
DR-8	Transfer Case Assembly	Revision B	9/26/86
DR-9	Wheel Track Support Layout		-

11.3 MODEL DESCRIPTION

Outline drawings of the 1/5 scale dynamic model are shown in Figures 11-11 and 11-12. Absent from these drawings are drawings of the track and its location on the model. These are shown in Figure 11-13 which is a layout of the wheel/track support suspension. Figure 11-14 shows the locations of the major drive components for the wheel/track system and the lift system components, including the location of the lift fan and ducting for the air cushion system. Components of the drive system include two drive motors, Catalog No. 6377, each rated at 3 HP, 4400 RPM and a Dayton Scale Model fabricated three speed transmission. Vehicle speed is manually adjusted by changing gear sizes on the transmission. Torque is transmitted through a drive shaft and clutch to a differential gear box at the rear axle which turns the rear axle and the paddle track. A second drive shaft from the transmission goes forward to the front wheels through a second differential gear box.

The lift fan motor was obtained from Porter Cable, Model 5182 rated at 22,000 RPM and belt drives a Bell Aerospace supplied lift fan at approximately 3500 RPM to produce the desired scale cushion pressure of approximately 14-11 psf, depending on whether the model is fully supported by the air cushion or partially supported by the wheels and track system.

Since the model power train and lift fan are electrically driven, an umbilical cord, approximately 75 feet in length using No. 9 gage electrical wire is used to transmit current and voltage to the model from a control box/rheostat for check-out and operation of the model. Eventually, more rigorous operational tests will be performed using the AFWAL test track which contains its own mobile power supply. When this occurs, the umbilical cord may not be required in its present form.

A wiring diagram of the drive and lift fan motors within the model is shown in Figure 11-15. Also shown are wiring connections for the model Instrumentation Package. This package consists of a Triaxial Accelerometer, a Triaxial Rate Gyro, and two pressure transducers located in the air cushion air duct and the air cushion plenum (the area enclosed by the fingers of the air cushion).

The triaxial accelerometer package contains three CEC model 4-204 bidirectional accelerometers rated at ±5g maximum. The rate gyro package consists of three identical rate gyros, designated Humphfrey Model RG02-2343-1 arranged for the measurement of vehicle rates along three mutually perpendicular axes. Gyro sensitivity is ±60 degrees per second. The pressure transducers are Celesco P15D units having a range of 25 psi. Each of the package outputs and the pressure transducer outputs are brought out to a terminal strip as shown in the wiring diagram, Figure 11-14. The gyro and accelerometer packages are located within the vehicle as close to the vehicle center of gravity as possible. Each package was checked during the vehicle check-out for wiring continuity and operation.

Other information regarding the full size and model scale parameters is listed in Table 11-4. The model air cushion is fabricated from black vinyl

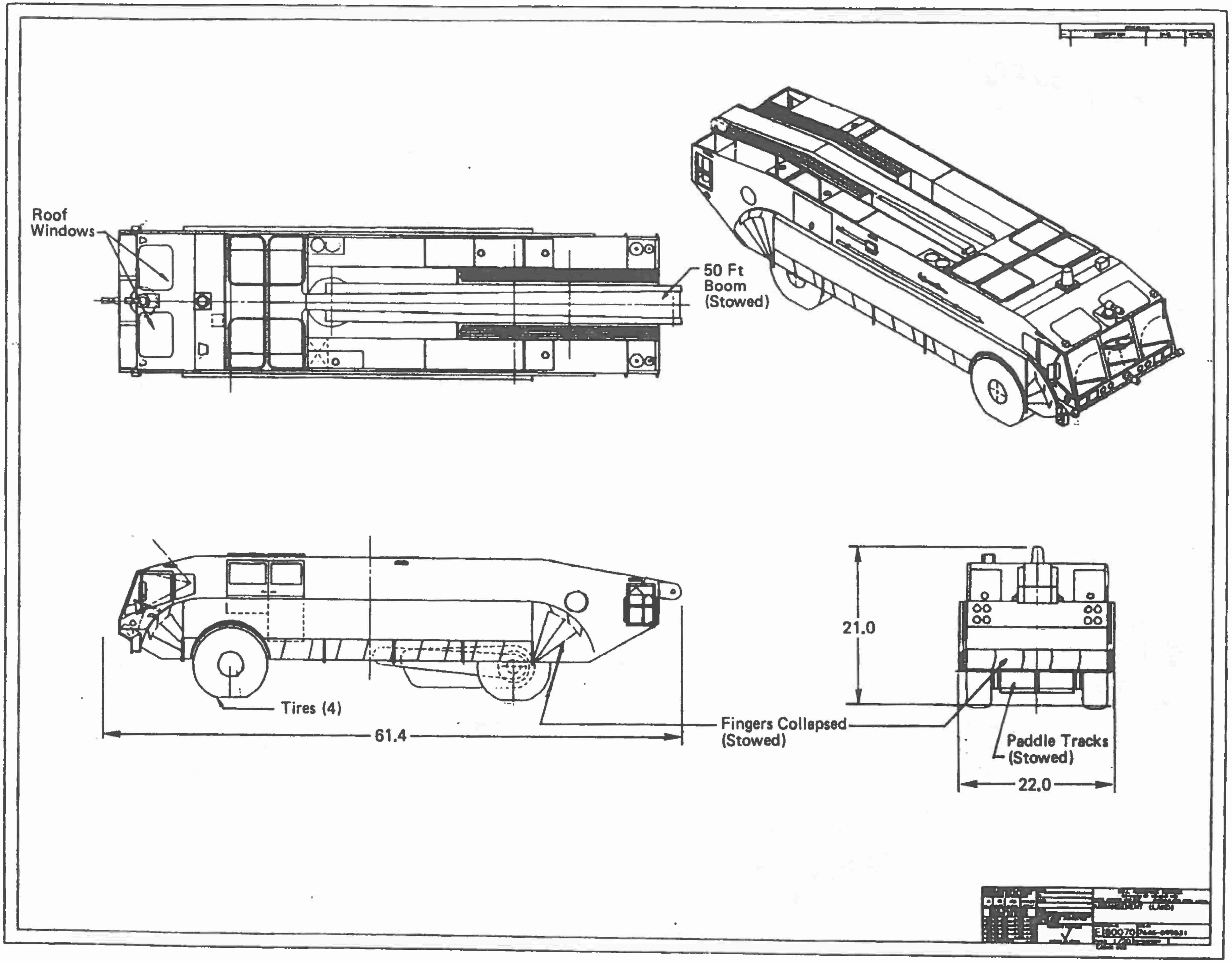


Figure 11-11. Model Arrangement (Land)

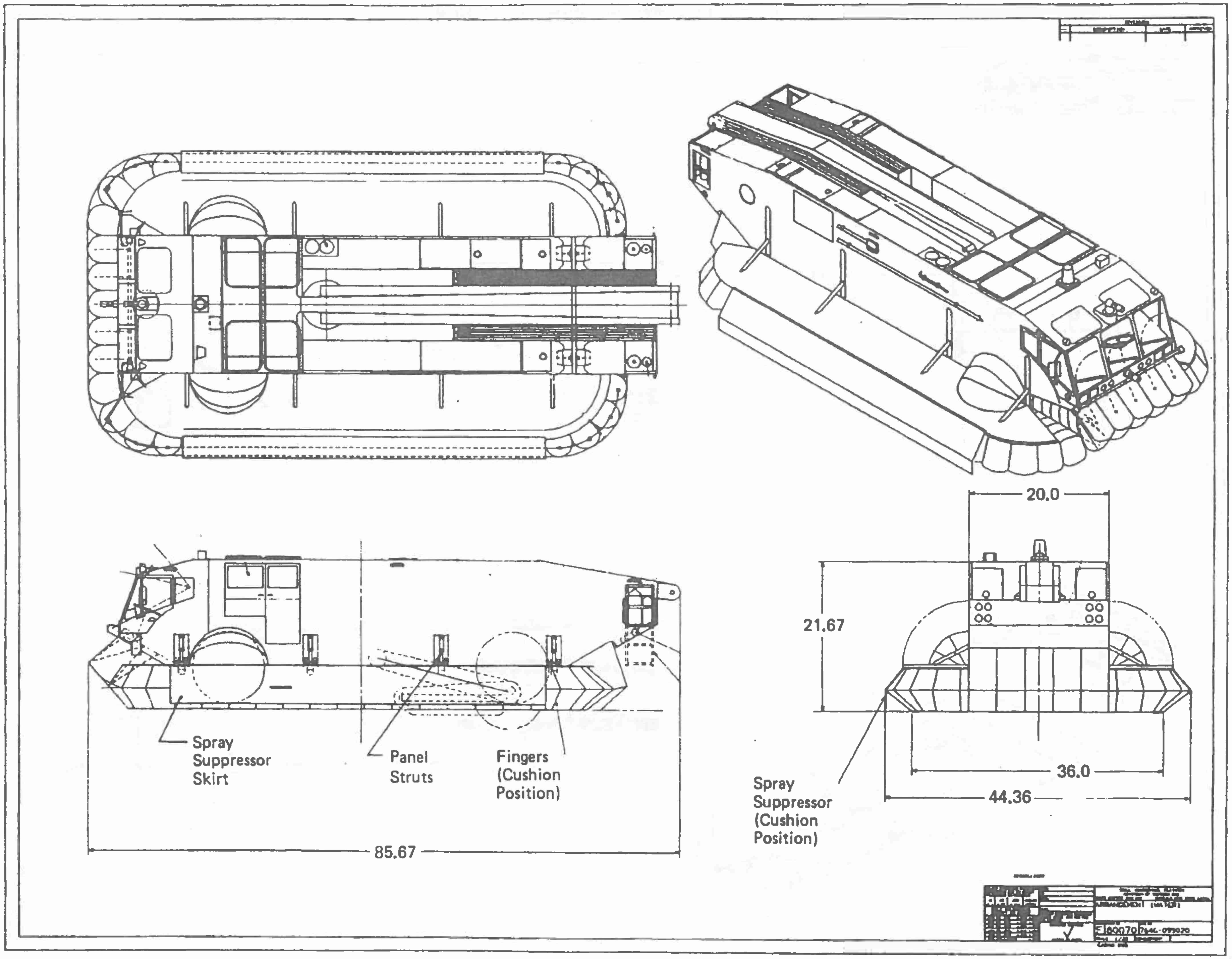


Figure 11-12. **General Arrangement (Water)**

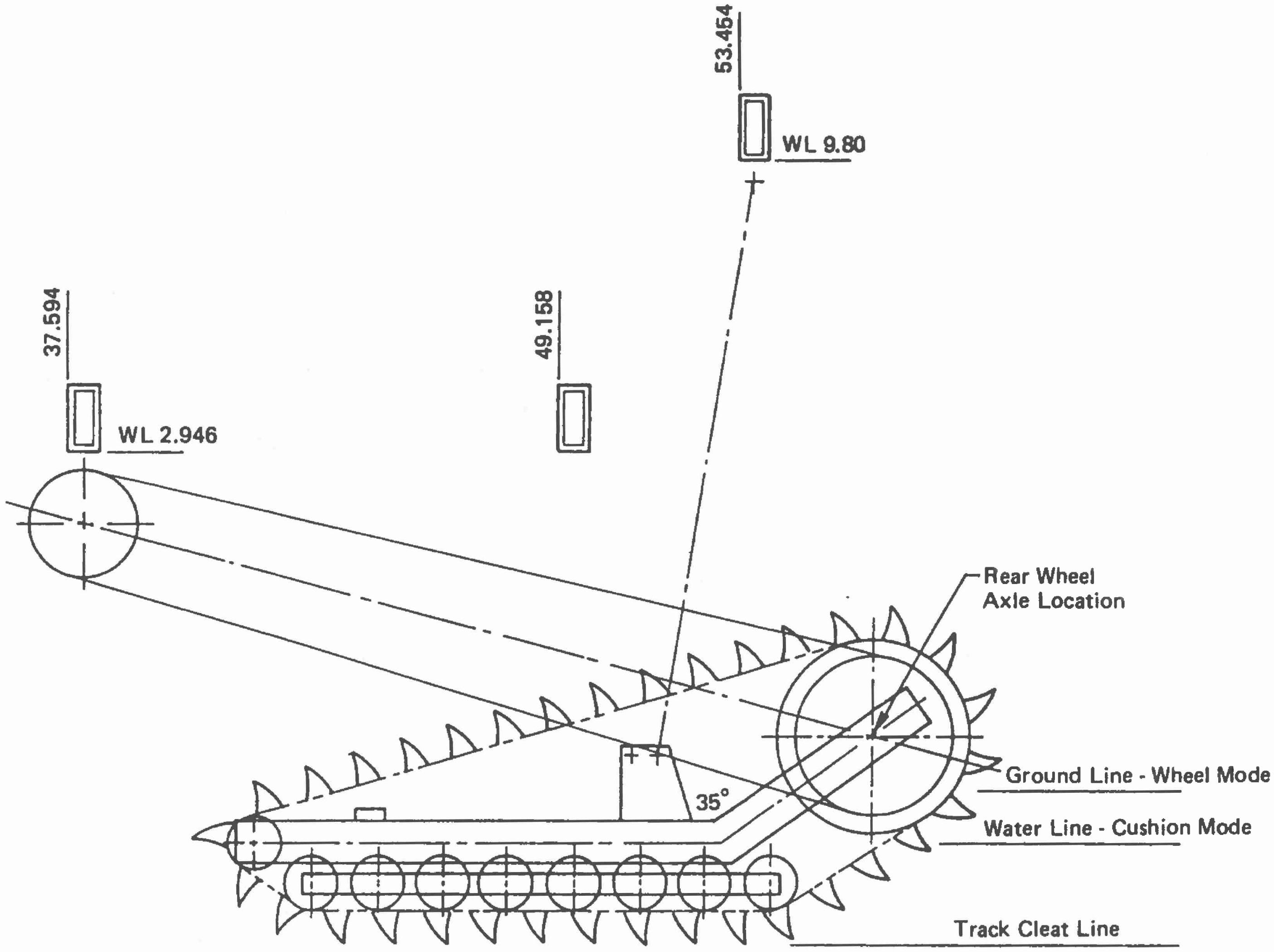


Figure 11-13. Layout of Wheel/Track Support

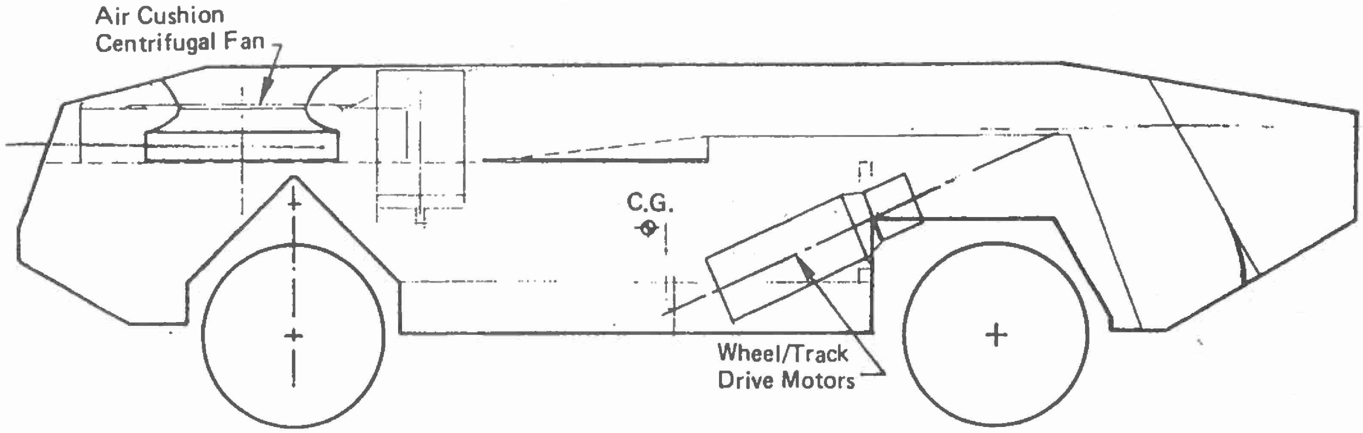


Figure 11-14. (1 of 2) Location of Air Cushion and Wheel Drive Components

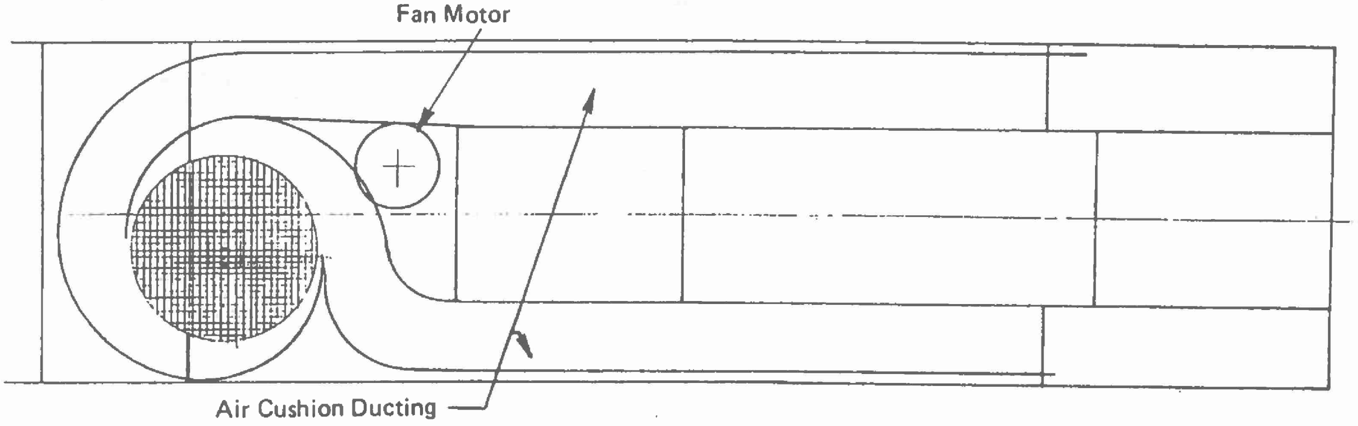


Figure 11-14. (2 of 2)

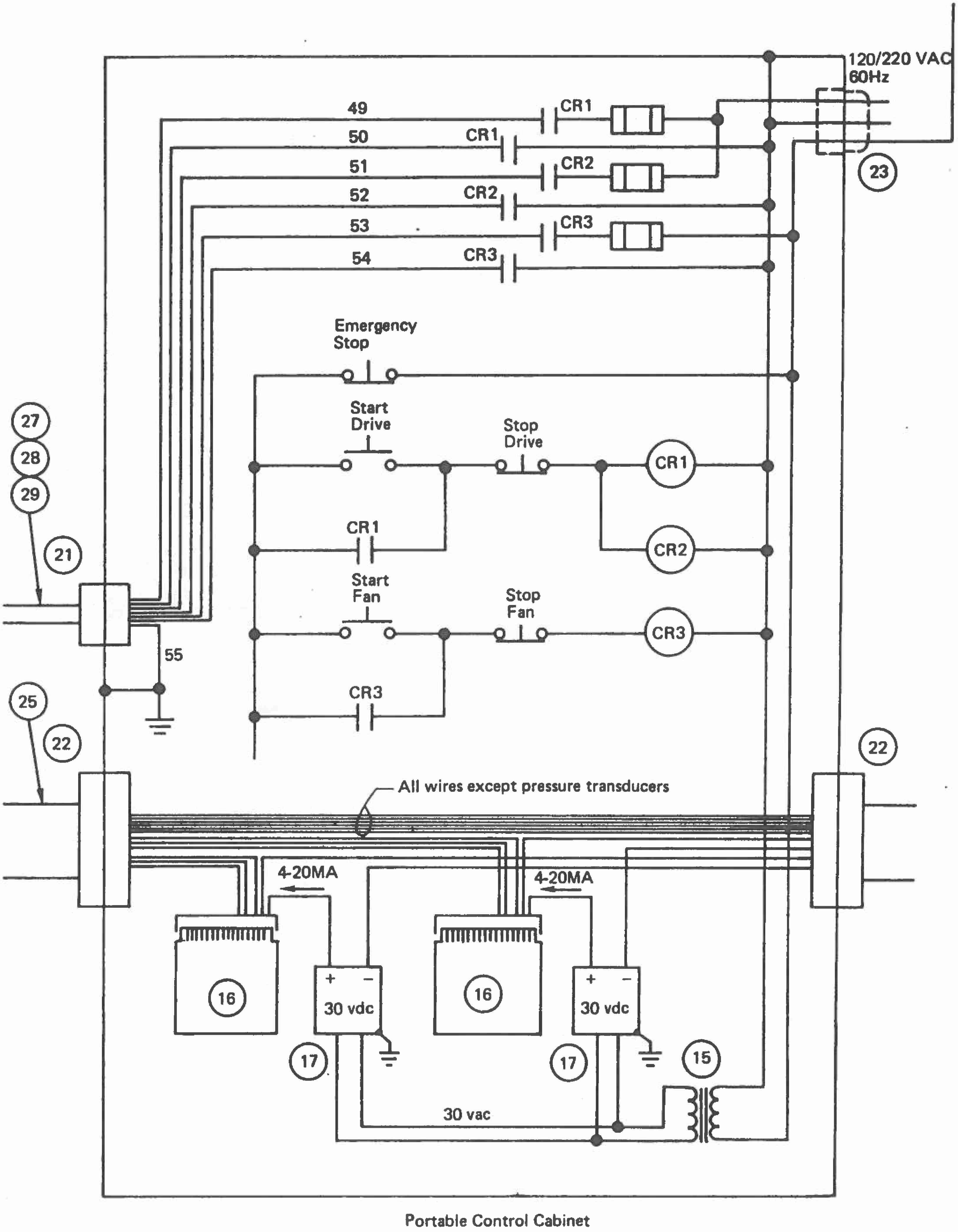
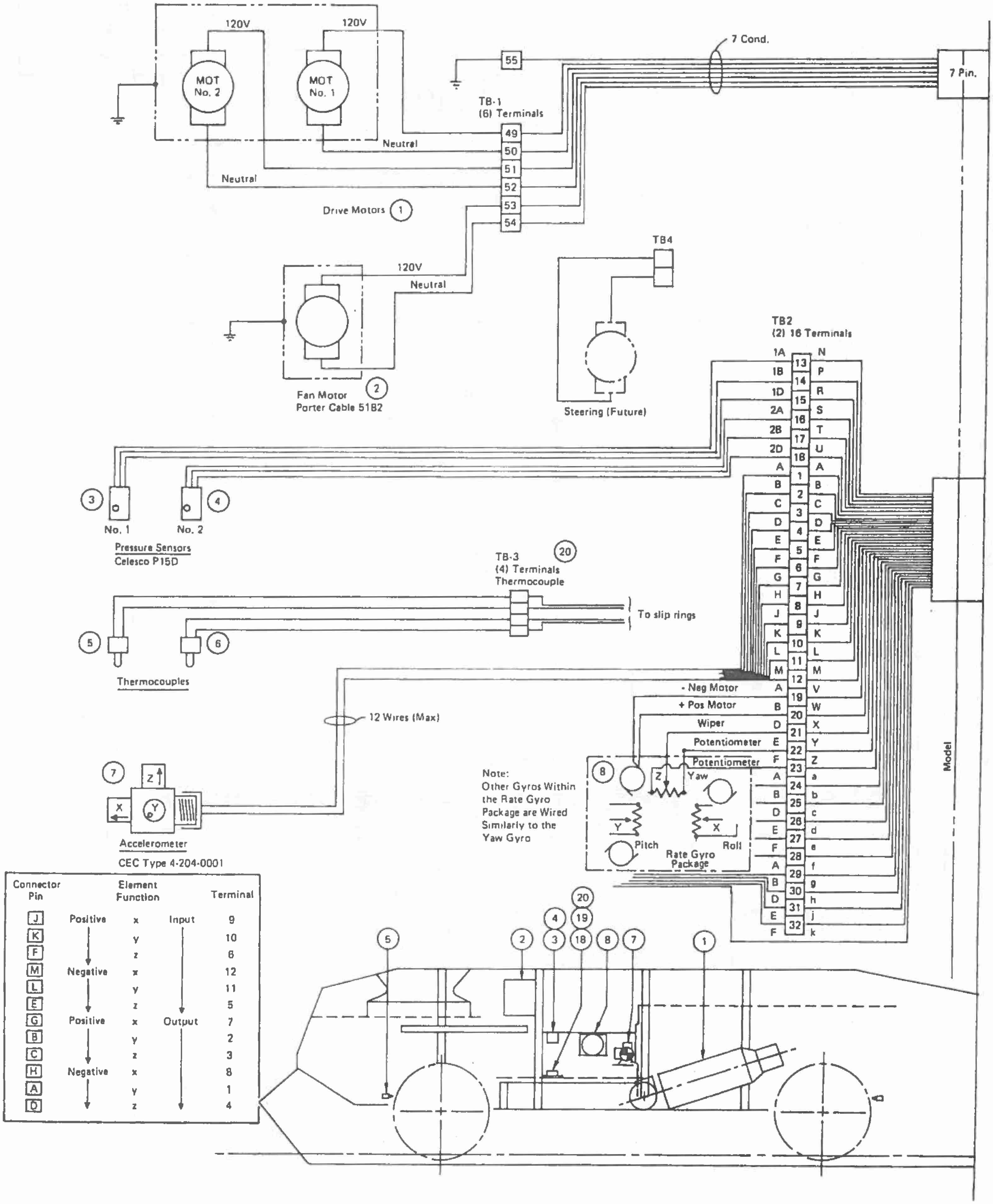


Figure 11-15. (1 of 3) ACCRV Electrical wiring diagrams



Connector Pin	Element Function			Terminal
J	Positive	x	Input	9
K	↓	y	↓	10
F		z		6
M	Negative	x		12
L	↓	y		11
E		z		5
G	Positive	x	Output	7
B	↓	y	↓	2
C		z		3
H	Negative	x		8
A	↓	y		1
D		z		4

Figure 11-15. (2 of 3)

Det	Qty	Description	Part No.	Mfgr.
1	2	Drive Motor w/Clutch		
2	1	Fan Motor 5182		Porter Cable
3	1	Pressure Sensor	PIS-D	Celesco
4	1	Pressure Sensor	PIS-D	Celesco
5	1	Thermocouple		
6	1	Thermocouple		
7	1	Accelerometer 3 Axis - 4.204	0001	CEC
8	1	Rate Gyro	Humphfrey RG02-2343-1	
9	1			
10	1			
11	2			
12	2			
13	2			
14	1			Variac
15	1	Transformer - 120V/30V ac		
16	2	Pressure Signal Demodulator	LCCD 420	Celesco
17	2	30 VDC Power Supply		
18	1	Terminal Block TB-1		
19	1	Terminal Block TB-2		
20	1	Terminal Block TB-3		
21	2	Connector - 7 Pin		
22	3	Connector - 36 Pin		
23	1	Connector - AC Plug and Receptacle		
24	50 Ft	Power Cord - 50 Ft @ 12 GA		
25	50 Ft	Cable Cond. GA		
26	30 Ft	Cable Cond. GA		
27	50 Ft	Cable Cond. GA		
28	50 Ft	Cable Cond. GA		
29	30 Ft	Cable Cond. GA		
30	1	Portable Cabinet		BVD
31	1	Control Box		BVD
32	1	Terminal Block – TB-4		

Figure 11-15. (3 of 3)

TABLE 11-4. FULL SCALE/MODEL SCALE COMPUTED VALUES

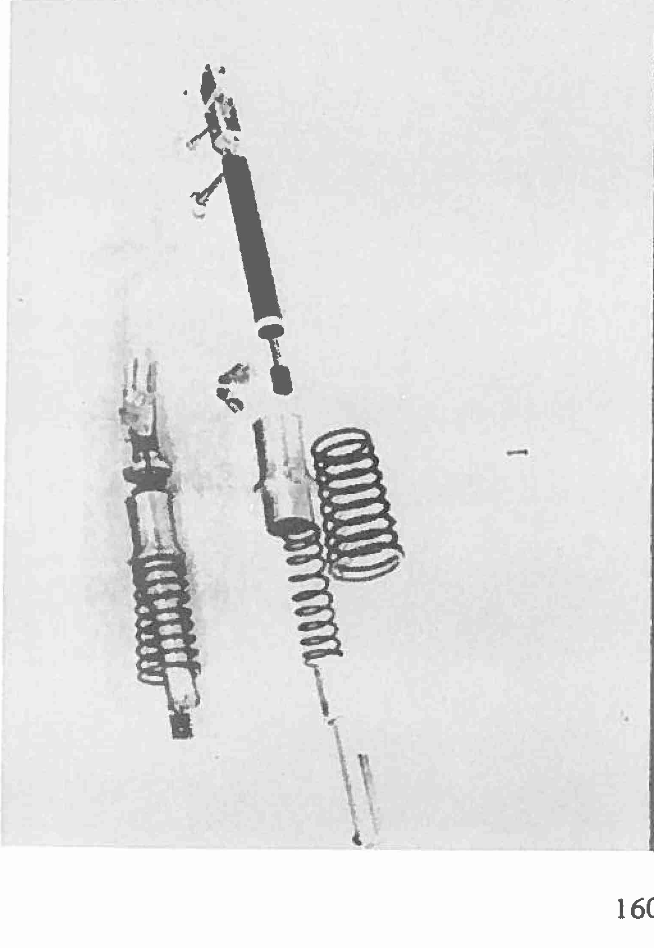
Parameter	Units	Full Scale	Model Scale
Length	in.	407	81.4
Width	in.	110	22.0
Height	in.	105	21.0
Wheel O.D.	in.	52.5	10.5
Track Width	in.	20	4.0
Track Cleat Height	in.	3	0.6
Wheel Base	in.	207	41.4
Gross Weight	lbs.	30,000	240
Moments of Inertia	$lb.in^2$		
Ixx		4.40×10^7	1.41×10^4
Iyy		1.74×10^8	5.57×10^4
Izz		1.66×10^8	5.31×10^4
CG Position	in.		
X		182.5	36.5
Y		0.6	0.1
Z		30.6	6.1
Cushion Pressure	psf		
On Cushion		71	14.2
Hybrid Mode		55	11.0
Tire Pressure	psi	40	8.0
Air Flow Rate	cfs	900	16.1
Fan Horsepower	HP	250 350 (Max.)	0.9 1.3 (Max.)
Track Thrust	lb	2200	17.6
Track Tip Speed	fps	42.8	19.1
Track Horsepower	HP	280	1.0
Total Horsepower	HP	700	2.5
Speed on Land	MPH	65	29.1
Speed Over Water	MPH	10	4.4
Obstacle Height	in.	12	2.4
Strut Stiffness	lb/in.		
Hybrid Mode		380	15.2
Wheeled Mode		760	30.4
Strut Damping Coefficient	lb-sec/ft		
Hybrid Mode		922	16.5
Wheeled Mode		1305	23.3

NOTE: The origin of the coordinate system is located at the vehicle front center, in plane with the lowest horizontal surface.

nylon, 0.103 in. thickness, using Bell Aerospace supplied templates for each of the air cushion fingers. The skirt material was purchased from Reeves Brothers, Spartanburg, SC. The model incorporates side spray skirts hung from the hinged side panels duplicating the arrangement on the full size vehicle design.

The model was photographed in several stages of fabrication, photos No. 1-10. The oleo pneumatic struts are shown partially disassembled in photo No. 1. The two drive clutches, the trailing arm assemblies, and the rear axle drive sprockets are shown in photo No. 2. Photo No. 3 illustrates one of the molded track belt units in place with one of the rear tires installed. An enlarged view of the track belt indicating height of cleat on track and sprocket drives is shown in photo No. 4. Photos No. 5 and No. 6 are two different views of the assembled wheel drive and suspension, with rear wheels and paddle track installed.

The model frame of 3/4 square aluminum tubing and the lift fan volute for air passage to the air cushion is shown in photo No. 7. The Bell Aerospace supplied centrifugal fan which supplies the air cushion air to inflate the cushion is illustrated in photo No. 8. A rear view of the wheels, paddle track and suspension components before installation of the body side and rear aluminum sheet panels is photo No. 9. The completed operational model is shown in photo No. 10, with air cushion inflated, and a scaled, non-operational boom and platform.



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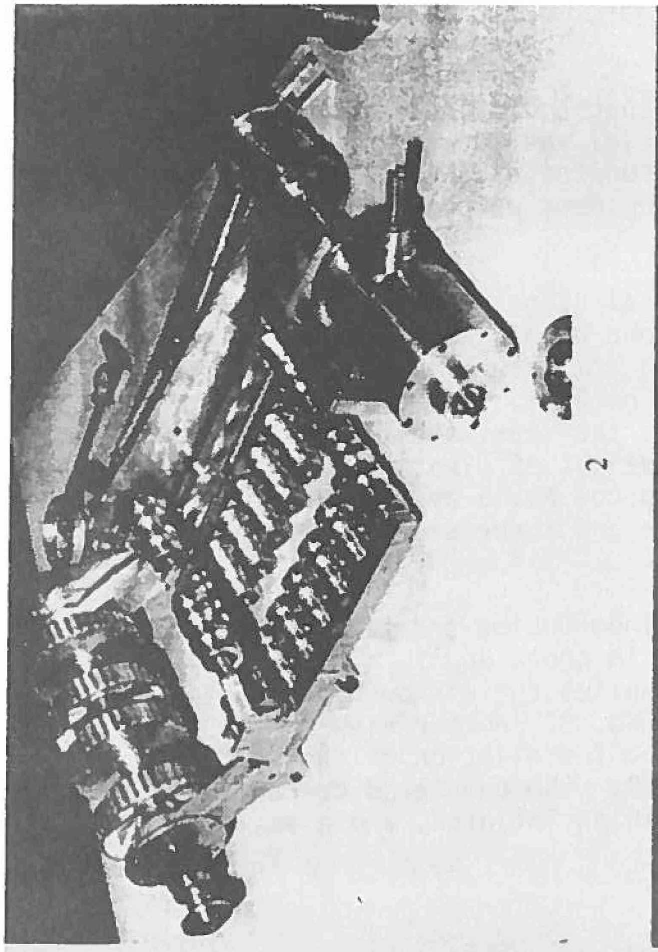

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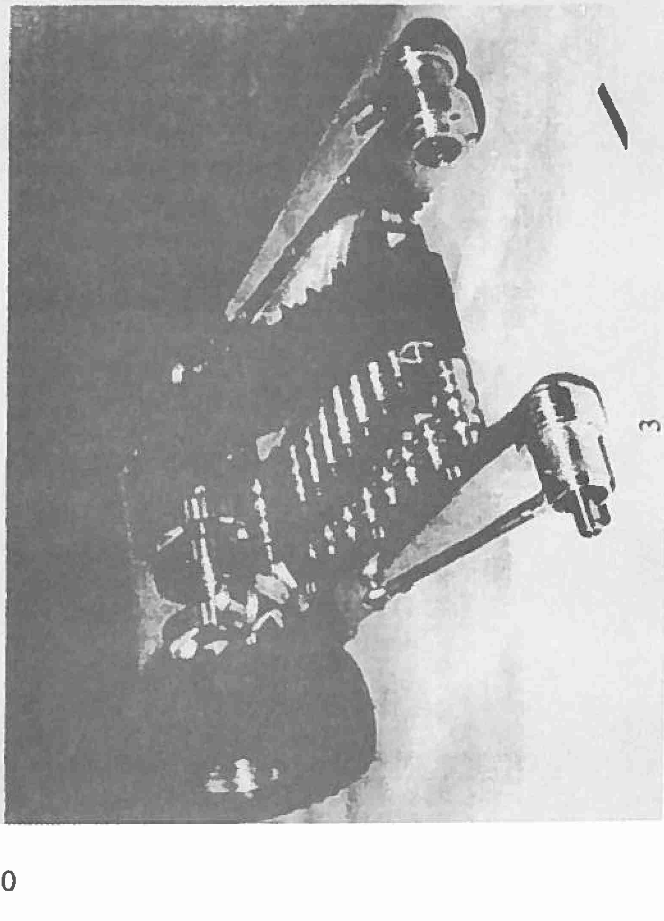

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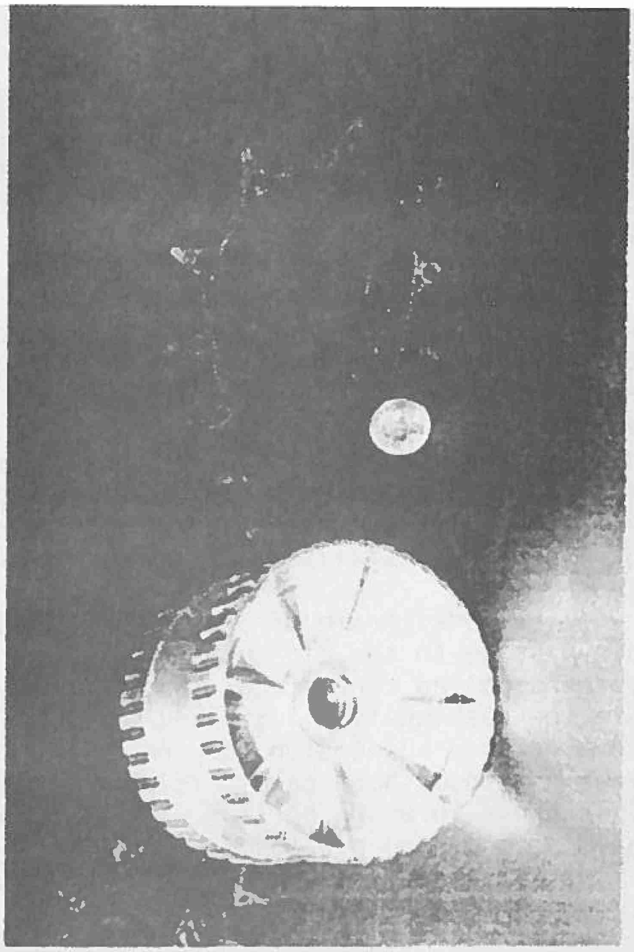

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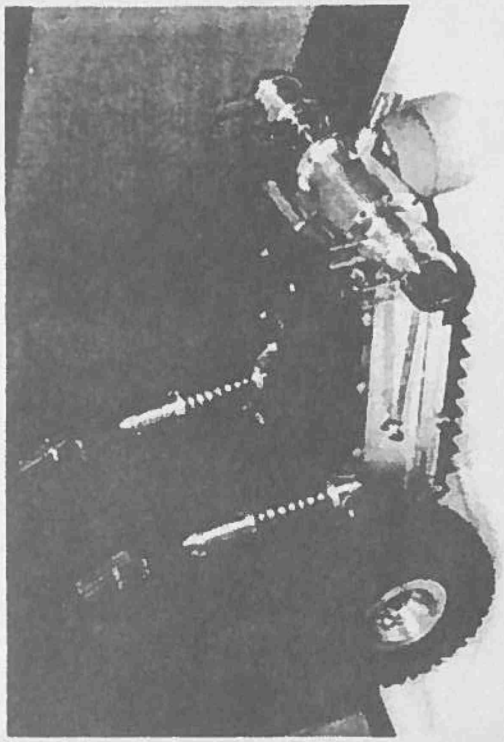

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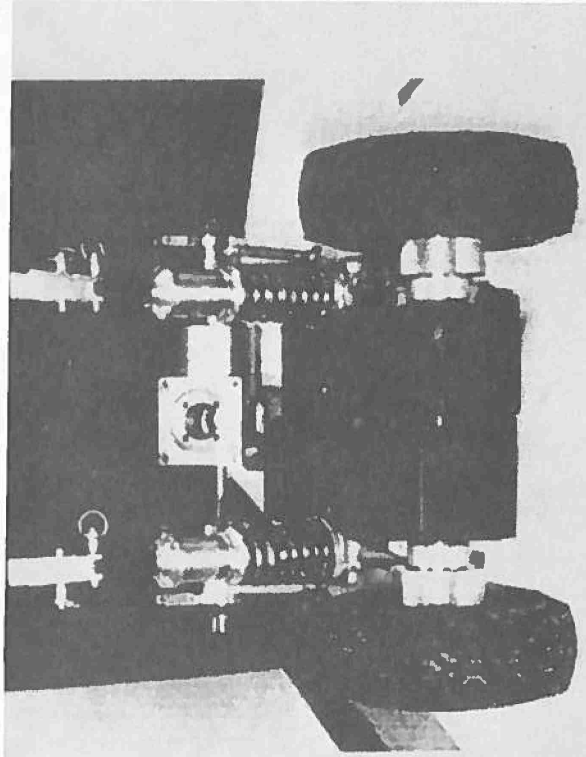

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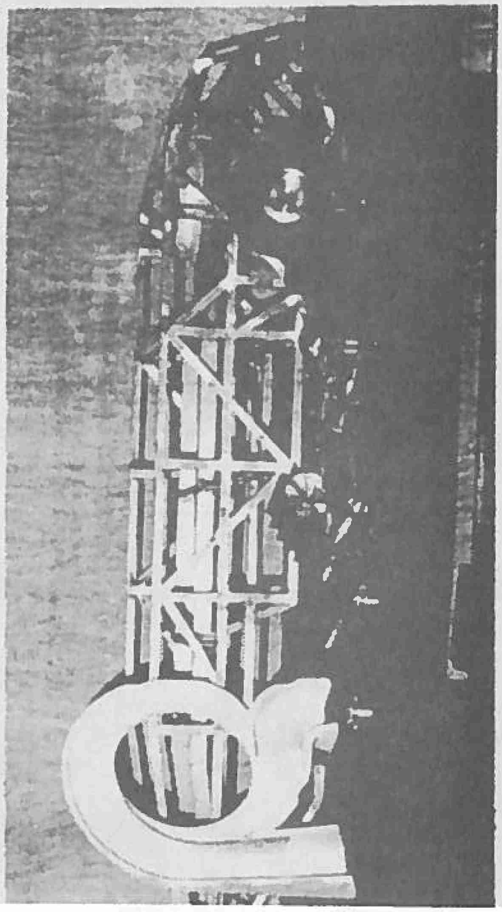

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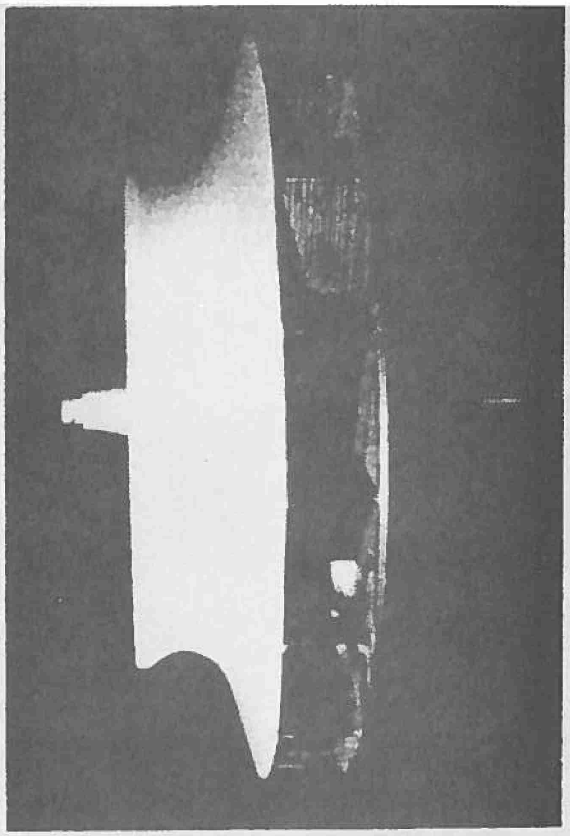

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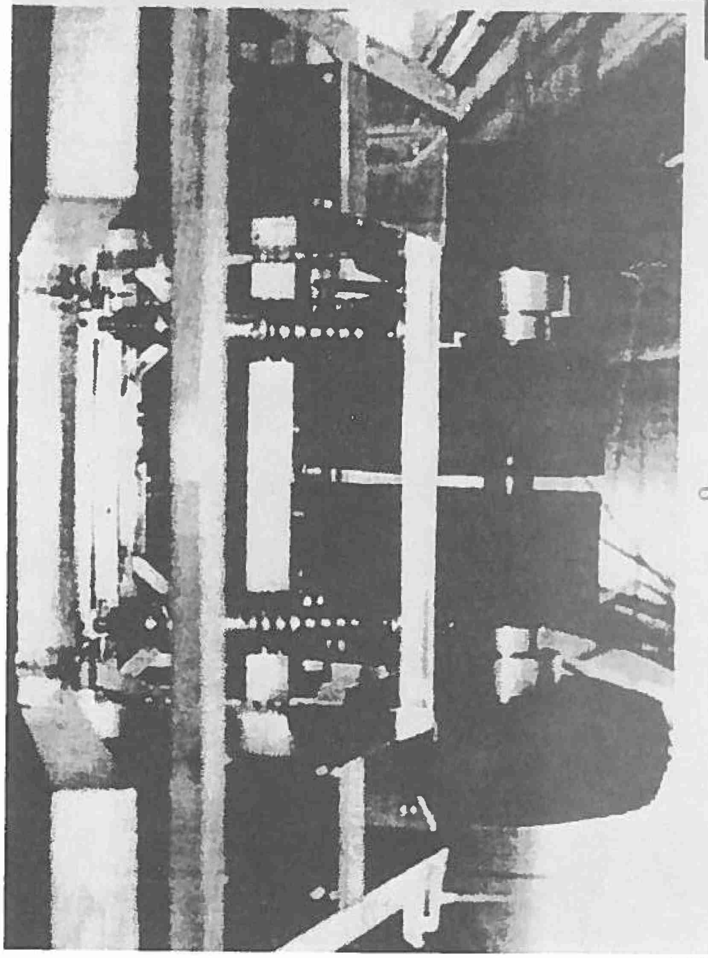

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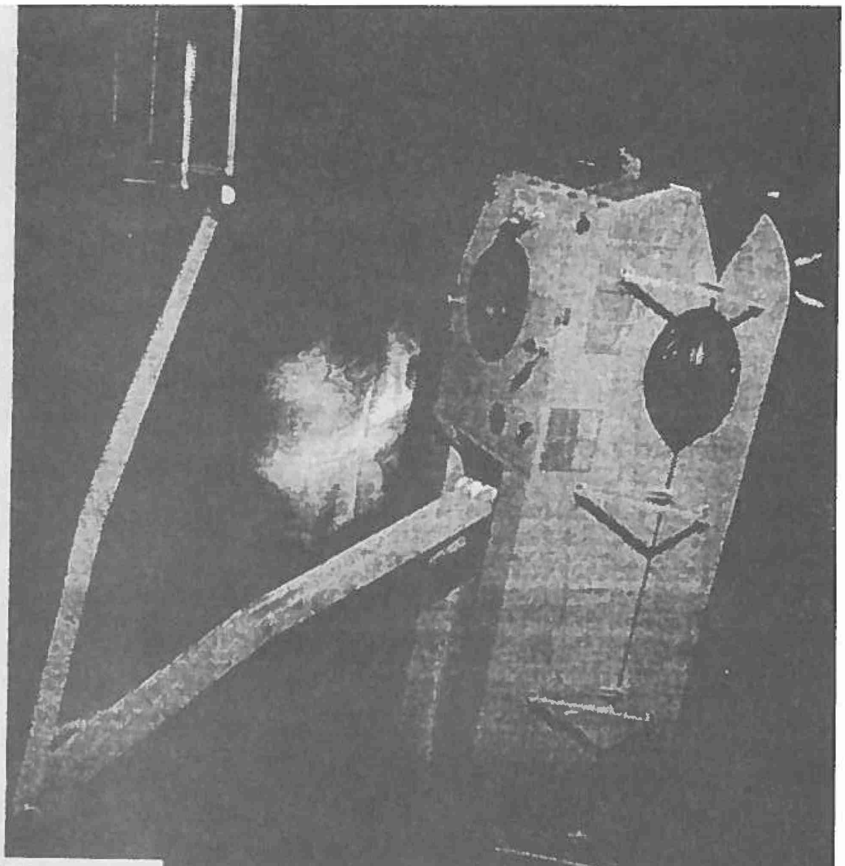

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11.4 ACCRV 1/5 SCALE MODEL DEMONSTRATION AND CHECKOUT PLAN

11.4.1 Objective

Generate a Demonstration and Checkout Test Plan for satisfying Statement of Work items listed in contract FY1456-85-02073, Air Cushion Crash Rescue Vehicle.

11.4.2 General

The reference contract lists the following items of work to be performed as part of Phase III, Subscale Model Construction and Checkout:

4.3.1.3.1 The subscale model checkout shall, as a minimum, include:

4.3.1.3.1.1 A functional demonstration of the sensors.

4.3.1.3.1.2 Determination of subscale model center of gravity (c.g.) and moments of inertia.

4.2.1.3.1.3 Demonstration of the air cushion augmentation system capability to support the total weight of the model and to traverse the ground surfaces identified as a CBR of 3 or higher. No attempt shall be made to scale the ground surface characteristics for this checkout. Only the size of the obstacles used in these tests shall be scaled.

4.3.1.3.1.4 Demonstration of the static stability with the weight of the model being supported by the air cushion augmentation system.

11.4.3 Test Plan

This test plan was intended to provide guidelines for the model builder (Dayton Scale Model) to accomplish the required checkout of the 1/5 scale dynamic model being fabricated at the model builder's facility. As such, some leeway in satisfying the SOW was possible, because there were several equal methods or procedures for performing and accomplishing the referenced task, i.e., the procedure or method suggested was not a requirement because other procedures maybe used to obtain the desired measurement or result. The only requirement was that each task be performed and witnessed, either by Bell personnel or by the Air Force Monitor, Randall Brown.

11.4.3.1 Task 4.3.1.3.1.1 A functional demonstration of the sensors.

There are 4 sensor types installed in the Model. These consist of:

1. A 3-axis accelerometer package located at the vehicle c.g.
2. A 3-axis rate gyro package located at the vehicle c.g.
3. A temperature sensor located in the cushion area.

4. Several pressure transducers (sensors) to read fan inlet pressure, plenum pressure and cushion pressure.

Since the words "functional demonstration" were interpreted as meaning operational demonstration, it was sufficient to energize each of the sensors with the appropriate input (pressure, temperature, acceleration, velocity) and record the sensor output. The pressure and temperature inputs occur when the air cushion system is operating so that a functional sensor demonstration for those two items was to operate the air cushion system and record outputs of those sensors. The accelerometer package has a maximum rating of 5 g's. A method for introducing a 3 or 4 g input was to raise one end of the model a small distance (<0.5 foot) and record the output from the package when the vehicle is released through free fall. An alternative was to input a scaled g level (e.g., 4 or 5 millivolts) corresponding to 1 g and record the output The rage gyro package has a maximum rating of ±60°/sec. Vehicle operation at a scaled speed will produce a recordable output; or a voltage can be applied to the gyro package input and the output recorded, while moving the vehicle at a constant rate. For the rate gyro and accelerometer packages, a voltage was input and recorded as a check for wiring continuity.

For the pressure transducers and thermocouples, continuity measurements of the wiring integrity were performed to verify wiring connections and transducer continuity.

This completed the functional demonstration of the sensors.

11.4.3.2 Task 4.3.1.2.1.2

Measurement of subscale model center of gravity (cg) and moments of inertia.

11.4.3.2.1 Longitudinal c.g. Location: Obtained front and rear axle weights by placing one axle on a scale or weighing device while the other was supported on firm ground. The desired location was obtained from the following formulas:

$$L_F = \frac{LW_R}{W}$$

$$L_R = \frac{LW_F}{W}$$

where W = total vehicle weight in pounds

W_R = weight on rear axle, pounds

W_F = weight on front axle, pounds

L = wheelbase or distance between wheel axles, ft. or in.

L_R = c.g. location from rear wheel axle, ft. or in.

L_F = c.g. location from front wheel axle, ft. or in.

Record distances L_R and L_F. As a final check, $L_R + L_F = L$.

11.4.3.2.1.1 The measured "X" position of the c.g. was 37.125 inches from the front edge of the vehicle.

11.4.3.2.2 Traverse c.g. Location: Obtain right and left side wheel weight and measure the transverse distance between right and left wheel ground contact points. The desired c.g. location was found from the formula:

$$S_1 = \frac{SW_2}{W} \text{ and } S_1 = \frac{SW_1}{W}$$

where S = transverse distance between wheel ground contact points, inches

S_1 = distance from left wheel ground contact point to c.g. location, inches

S_2 = distance from right wheel ground contact point to c.g. location, inches.

W_2 = right side wheel weights, pounds

W_1 = leftside wheel weights, pounds

W = total vehicle weight in pounds

Record distances S_1 and S_2. As a final check, $S_1 + S_2 = S$.

11.4.3.2.2.1 The measured "Y" distance of the c.g. to the right wheel ground contact point was 0.1 inch.

11.4.3.2.3 Vertical c.g. Location: Weight front wheel axle while raising rear wheel axle to an arbitrary height (assume 2 ft.). The desired location of the vertical c.g. was obtained from the formula:

$$L_{R'} = \frac{W_{F'}\ L'}{W} = \frac{W_{F'}}{W} \sqrt{L^2 - N^2}$$

where L_R' = horizontal distance from c.g. to rear wheel.

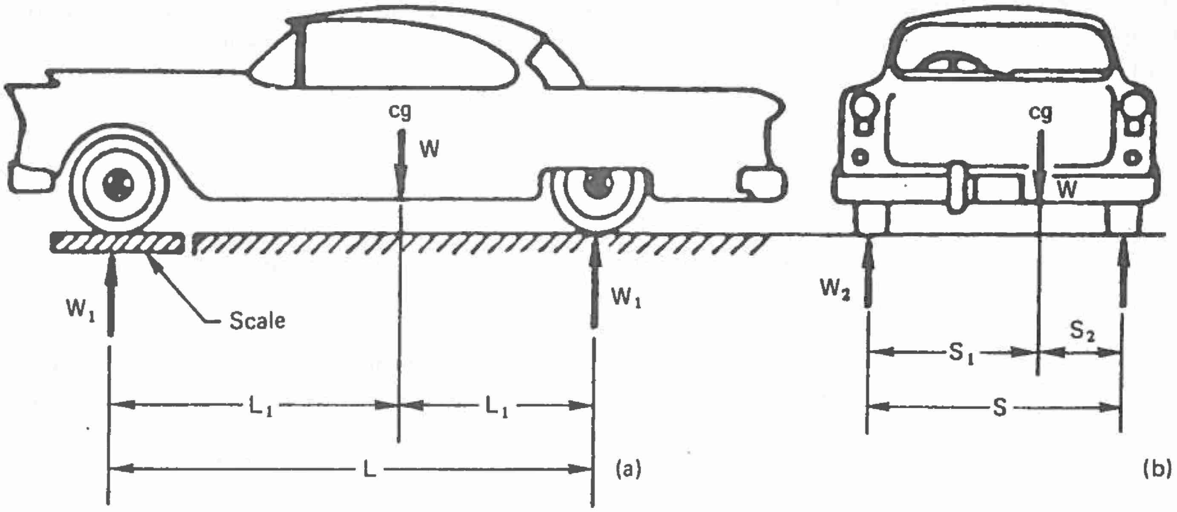
W_F' = front wheel axle weight when rear axle is elevated, pounds

L = total weight of vehicle, pounds

Refer to sketch (Figure 11-16) for further details.

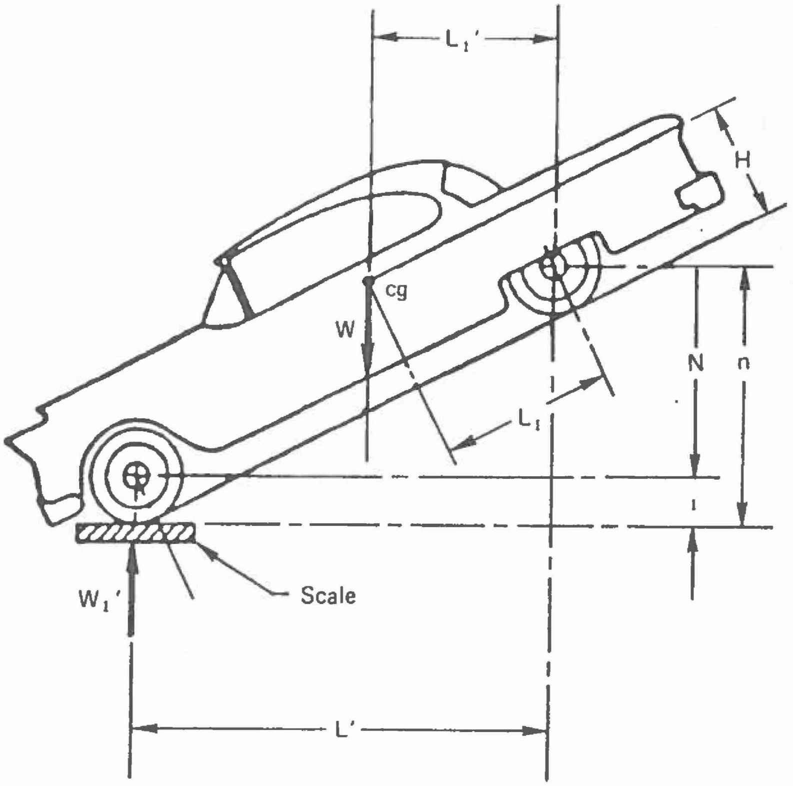
Record vertical c.g. location.

11.4.3.2.3.1 The measured "Z" distance from vertical c.g. to the bottom edge of vehicle body was 3.47 inches.



Longitudinal

Transverse



Vertical

Figure 11-16. C.G. Locations

11.4.3.2.4 Moments of Inertia Measurement: This method, torsional oscillation, determines inertia moments around a vertical axis. Suspended the model on two flexible wires of length L, located a wheelbase apart, A, and applied a torsional moment of small angular displacement. Measured the time, T, of one complete oscillation. The inertia moment around the vertical axis was obtained from the formula:

$$I = \frac{W}{L} \left[\frac{AT}{4\pi}\right]^2 \text{ lb-ft-sec}^2$$

where W = total model weight, pounds

L = length of suspension wire, feet or inches

A = distance between suspension wires, feet or inches

T = time of one complete oscillation, seconds

π = 3.1416

Record the moment of inertia, I_{zz}.

11.4.3.2.4.1 Following these procedures, the measured moments of inertia were as follows:

$I_{xx} = 1.53 \times 10^4$ lb in.^{2}

$I_{yy} = 7.46 \times 10^4$ lb in.^{2}

$I_{zz} = 7.10 \times 10^4$ lb in.^{2}

11.4.3.3 Task 4.3.1.3.1.3 Demonstration of the air cushion system capability to support the total model weight. Demonstration of the model's capability to traverse ground surfaces identified as having a CBR of 3 or higher.

Part 1 - To demonstrate that the air cushion supports the total vehicle weight, the original plan was to excavate material around the vehicle in order to support the model solely by its inflated air cushion. It was decided instead to remove the wheels and track from the vehicle and place the model on a flat surface plate and note the increase in height which occurred when the air cushion was inflated, after weighing the vehicle with the wheels and track unattached, but including the wheels and track in the total model weight. The measurement from the top edge of the model to the flat surface plate was approximately 21.75 inches with the wheels and paddle track loosely stacked on the top of the vehicle. Total model weight with these conditions was 245 pounds.

Part 2 - To demonstrate vehicle mobility over surfaces whose CBR rating is greater than 3, it was necessary to operate the model in swampy or muddy terrain. Model speed was not measured, nor was the terrain precisely scaled for this demonstration. In looking for suitable terrain, the application of the full size vehicle was considered, i.e., the full size vehicle will be used off runway and beyond, over hilly and slanted land surfaces which may be wet or dry, with obstacles as large as 0.9 foot in height or depth. Terrain surrounding the model builder's facility was carefully examined for this demonstration, and a test route prepared, which was within the model's capacity to demonstrate it's mobility. Demonstration runs were operated with the air cushion initially deflated, with only the wheels and track system energized. When terrain was encountered which causes the model to falter or become unable to move forward, the air cushion was energized to lessen the apparent ground pressure being generated by the model, and the terrain which caused the original stoppage was retraversed to demonstrate the air cushion augmentation capability.

The model was operated through mud and snow over a swampy lot behind the model builder's facility. This lot is approximately 90 feet in length and about 30 feet wide. The ground was relatively flat, but strewn with small rocks and other debris. The afternoon of the demonstration, wet snow was falling. The ground surface was frozen, due to rain falling during the day before. Air temperature was near freezing and the falling snow combined with the vehicle being run over the surface, soon made a quagmire of mud and water, about 3 inches deep.

The model vehicle was operated on wheels and with the track deployed over this surface several times, and the model bogged down on each of the runs approximately halfway through the course. At least four attempts were made to traverse the surface, with each ending in the vehicle getting stuck and not being able to move forward. After the fourth try, the model was retrieved, and the air cushion inflated. The model was placed back at the starting point, and operated again through the test course. The model was able to traverse the mud and snow to the end of the course successfully. The model was turned around and operated back over the course to the starting point without bogging down or getting stuck.

This operation was repeated again i.e., the model vehicle with air cushion inflated was operated again over the quagmire and negotiated the course successfully. Note that with the air cushion off loading the tires and track system, the vehicle was able to move through the mire. The critical parameter is the percentage weight supported by the cushion. If the percentage is too high, there won't be sufficient traction for the tires and track to move the vehicle - if percentage is too low, the resistance of the mire overcomes the tractive force developed by the wheels and track, and the vehicle becomes stuck or bogged down.

The model was cleaned externally and brought inside to perform some further operational checks. The model was operated over a sloped surface to check grade climbing capability. An eight foot board was elevated at one end to produce a 5% grade (elevated 5.64 inches). The model easily climbed the grade. The elevation was increased to 10% (elevated 11.6 inches) the model climbed the grade without any problem. The grade was increased to approximately 13 degrees with a block of wood about 20 inches in height. Again the model easily climbed the grade.

Next, a series of craters were constructed from plywood sheets and blocks of wood to simulate the crater profiles A, B, C of Figure 52.3.2 (Final Report). The model was operated over these profiles several times. The next morning, at the same facility (Dayton Scale Model) the model was operated over a 2" x4" board obstacle inside the building and then operated in the facility parking lot (gravel, stones, about 2 inches of snow) for the benefit of the Air Force observers. Video tapes of all checkout demonstrations were recorded and are available for viewing.

Prior to performing the mobility checkout on land, the model was placed in a small pool approximately 15 feet long, and 10 feet wide filled with water to a depth of about 1 foot, to check the propulsion capability of the paddle track system. The paddle track was energized and the air cushion deployed in the water and spring scales were used to estimate the thrust produced by the paddle track. In each case, the vehicle moved forward when the track was energized, although thrust measurements varied between about 2 pounds and 8 pounds. It became apparent that a larger pool was necessary to avoid the turbulent wave interference due to the narrow width of the pool. The model appeared to be stable in water (no tipping) and it did support it's own weight while on air cushion. No further watertests were conducted.

11.4.3.4 Task 4.3.1.3.1.4

Demonstration of the static stiffness with the weight of the model being supported by the air cushion system.

This task was completed during the earlier Task of 4.3.1.3.1.3 (Part 1). Basically, it consisted of measuring vehicle height changes as fan speed and vehicle weight changes, commonly referred to as static heave stiffness. The procedure follows:

1. With air cushion inflated and a known model weight (245 lb.), and with the model's air cushion supporting the total model weight, fan speed was adjusted to a maximum value (3500 RPM). Vehicle height above ground reference was measured and recorded.
2. Fan speed was reduced to nominal value (3000 RPM). Vehicle height above ground reference was measured and recorded. Model weight, from Step 1 above, was not changed.
3. Fan speed, as used in Step 2, was maintained. Model weight was reduced to 184 pounds. Vehicle height above ground reference was recorded.
4. Fan speed was raised to maximum value (3500 RPM) and Step 3 was repeated at the reduced model weight.
5. Model weight was increased from 245 pounds to 264 pounds. Fan speed was maintained at maximum value and vehicle height above ground reference was measured and recorded.
6. Step 5 was repeated at reduced fan speed of 3000 RPM. Vertical height from ground reference was measured and recorded. The values obtained from the above test demonstrations were plotted to obtain two smooth curves of vehicle height versus vehicle weight at two constant fan speeds. Results of this task are shown in Table 11-5 and Figure 11-17.

Table 11-5. Height Change Versus Weight and Fan Speed

Model Weight, lbs	Fan Speed (rpm)	Vehicle Height, inches
245	3500	21.89
245	3000	21.81
184	3000	21.88
184	3500	21.95
264	3500	21.87
264	3000	21.79

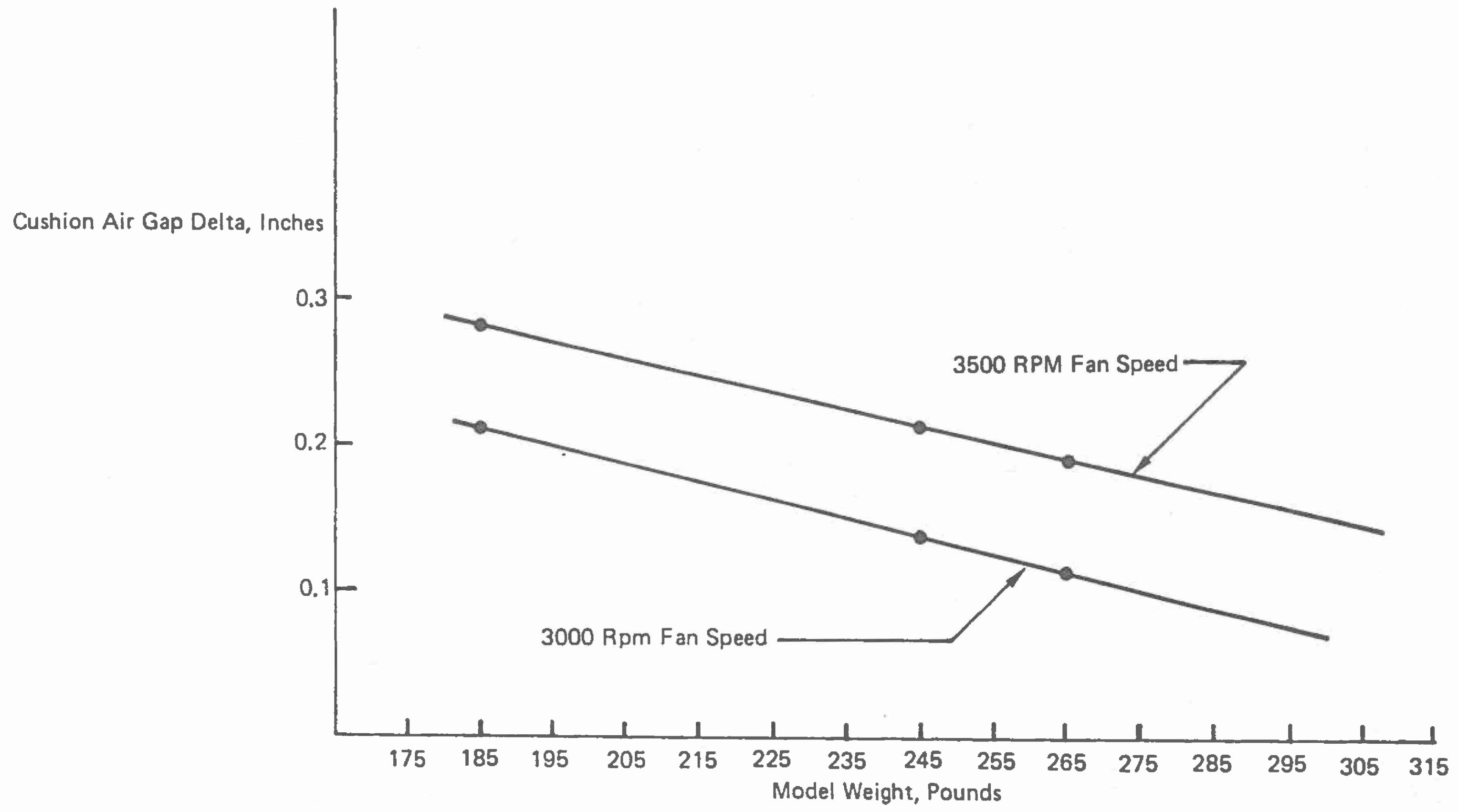


Figure 11-17. Change in Cushion Airgap with Variation in Fan Speed and Model Weight

12.0 RELIABILITY/MAINTAINABILITY

12.1 Introduction

A general Life Cycle Cost apportionment used by the Air Force for currently operational systems is 25% for system acquisition, 10% for system operation and 65% for system supportability. Supportability of the ACCRV is obviously an area requiring early design consideration to preclude unacceptable support costs after system deployment.

Two keystones of support costs are component and system Reliability (R) and Maintainability (M). These characteristics must be considered from the initiation of the design to preclude expensive design modifications late in the development test phase or the acceptance of low availability and high support costs over the life of the deployed system. These support costs (personnel and their skill requirements, maintenance, training, technical manuals and support equipment, for example, will be a direct result of the ACCRV R&M characteristics developed during design creation.

Consequently, our Reliability and Maintainability engineering disciplines have worked closely with our designers in the transition of the ACCRV conceptual to preliminary design configuration.

The R/M participation in the selection of components and in the evaluation of subsystem interface effects has been, to date, limited for the most part, to a supportability/logistical engineering judgement evaluation rather than to a formal Logistic Support type of analysis. With the exception of two subsystems (the air cushion lift system and the marine drive) design components/systems generally fall into two categories:

a. Non development items (NDI), or
b. Conceptual systems where some additional design detail will be required to make any meaningful R/M predictions.

Notwithstanding the NDI category of most of the components/subsystems of the preliminary design, R&M formal analysis has not been conducted as no mission profile has been defined for the system. The selected powerplant, the Detroit Diesel 8V-92TA engine is a good illustration for this reasoning.

A multitude of data exists for this commercial/military application engine. Reliability and Maintainability predictions of the highest confidence can be projected from this data if a mission duty life cycle is defined for the engine. Required parameters for the analysis would include maximum engine speed, frequency of use at this speed, duration of operation at this and other speeds and environmental factors during operation and field deployment. Although this engine is selected partially for R&M general characteristics, no meaningful ACCRV predictions can be projected for it without development of a fairly detailed mission profile.

The second category includes items which are not NDI and will require more design detail for R&M projections. The rescue boom is an example of this category.

The third category comprises two systems for which there may not be readily available industry data but with which Bell has in depth experience with comparable systems sufficient to provide similarity projections. These systems are the Lift (Air Cushion) and Marine Drive. Pertinent data for them is presented in the two succeeding subsections. The fourth subsection diagrams the other subsystems of the ACCRV and these diagrams will provide the baseline for future R/M models, allocations and predictions.

12.2 Lift (Air Cushion) System

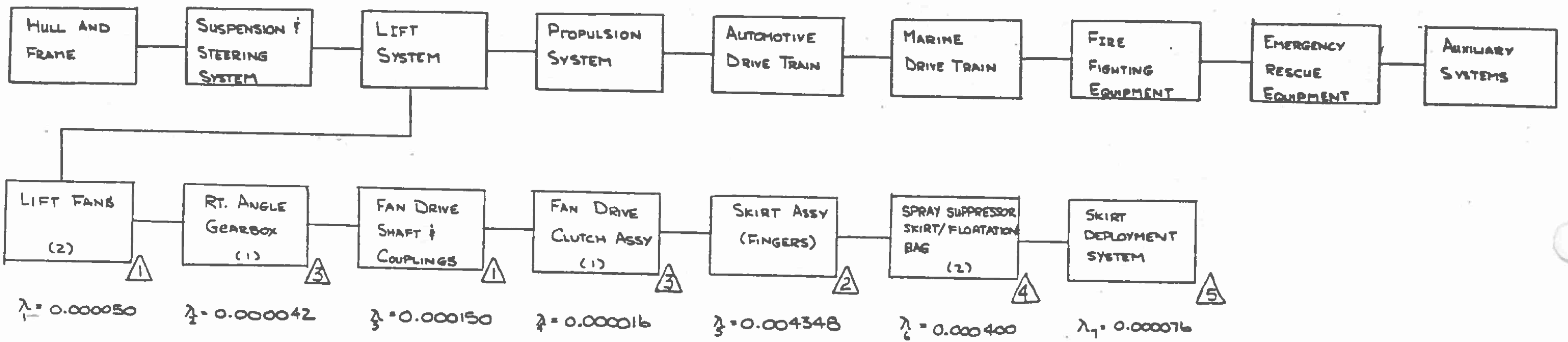
The ACCRV Lift System provides for 'on-cushion' operation during either over-water or on-land (on soft surfaces) conditions. Reliability of the Lift Systems with its engine driven lift fans, skirt assembly and other lift system equipment, is depicted by the reliability block diagram of Figure 12-1.

Failure rate data for ACCRV Lift System equipment was extracted, for the most part, from Bell Reports 7647-932001 (Reliability and Maintainability Report, LACV-30) and 7614-932002 (LCAC Reliability and Maintainability Allocation, Assessment and Analysis Report). These reports are, in turn, based on over 20,000 operating hours accumulated over a ten year period, and in various operating environments, for ACV craft such as SK-5, Voyageur and SR.N5. Failure rate data for selected other lift fan drive train components and for ACCRV unique skirt deployment system equipment, was extracted from generic data sources (FARADA, NPRD-1, AVCO) and applied to the reliability block diagram to predict ACCRV total lift system reliability.

The predicted failure rate of 5082 failures/million hours and associated MTBF of 197 hours can be mitigated by two factors:

a. RCM measures - The major contributor to the lift system total failure rate is the skirt assembly. Consideration of RCM measures during follow-on full scale design and prototype testing will provide the necessary data to allow an optimum schedule to be defined for skirt assembly replacement. This changeout interval may occur, for example, at every 200 hours of lift system operation, before skirt finger wearout or failure is detected.

b. Low Lift System Operating Hours - Because operation of the lift system is required only during over-water or hybrid modes of land operation, total lift system operating times are anticipated to be only a small percentage of the total ACCRV operating times. The net effect then, will be to reduce the impact of lift system reliability on the total ACCRV reliability.



$\lambda_{TOT} = \sum_{i=1}^{7} \lambda_i = 0.005082$ failures/hr

MTBF = $1/\lambda_{TOT}$ = 197 hrs

△1 BELL RELIABILITY & MAINTAINABILITY REPORT, LACV-30 (7467-932001)

△2 BELL RELIABILITY & MAINTAINABILITY ALLOCATION, ASSESSMENT & ANALYSIS REPORT, LCAC (7614-932002)

△3 FAILURE RATE EXTRACTED FROM FARADA

△4 BELL ENGINEERING ESTIMATE BASED ON REFERENCES △1 AND △2

△5 AVCO, NPRD-1, BASED ON PARTS COUNT ANALYSIS FOR ACTUATORS, VALVES, LINES & FITTINGS.

Figure 12-1. Reliability Block Diagram - Lift System

12.3 Marine Drive Train

The ACCRV Marine Drive Train provides the over-water propulsion and steering and supplements the automotive drive train during land operations on soft/marginal terrain. When not required, the Marine Drive Train is retracted away from the ground and into the underside of the vehicle.

To develop a failure rate prediction for the ACCRV marine drive train system, previous reliability predictions developed for other Bell tracked vehicle designs were heavily relied upon for equipment failure rate data. These sources include Bell Reports 7615-950003 (LVT(X) Reliability, Availability, Maintainability and Durability Analysis) and 7619-927001 (MPWS Final Report, Conceptual Design Study) and are based in part on test/field data for tracked vehicles reported in the TARCOM Major Item RAM-D Summary (August 1980). Generic data sources (Avco, NPRD-1) were also utilized to develop failure rate data for the actuation/retraction system. The reliability block diagram for the marine drive train is shown by Figure 12-2.

During water/hybrid land operations the track is deployed and provides the primary tractive power. However, because during land operations the marine drive train continues to operate, but is retracted away from the ground and is essentially subjected to a 'no-load' condition, equipment stress levels are diminished. This can be assumed to translate the predicted failure rate of 3515 failures/million hours and associated MTBF of 285 hours to be a pessimistic viewpoint or worst case condition and also a compensatory factor for any uncertainties due to the conceptual nature of the design.

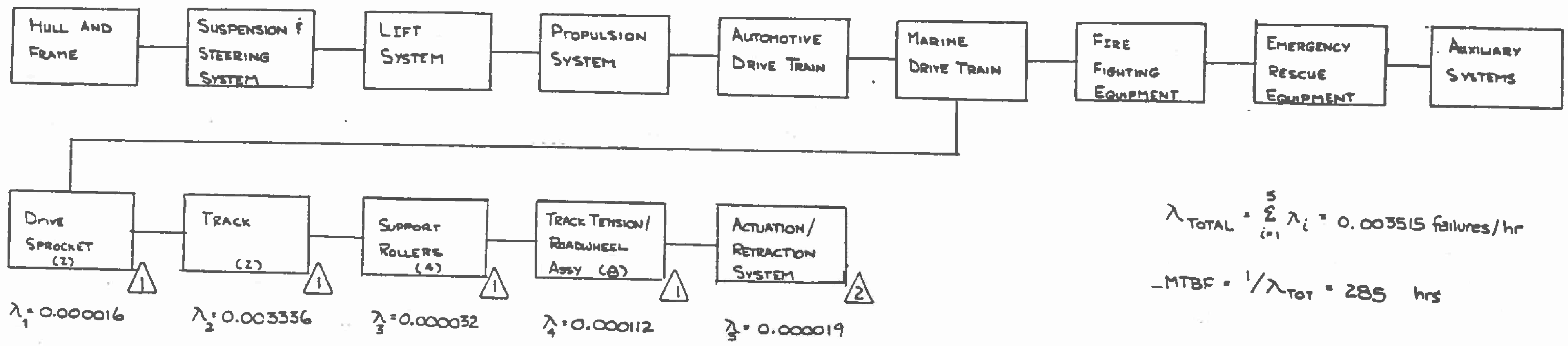
12.4 Other Systems

Figures 12-3 through 12-9 illustrate the remaining ACCRV systems and subsystems. These diagrams will provide points of departure for a comprehensive R/M analysis of the preliminary design as it matures toward prototype status. Again, NDI's and Bell's proven air cushion technology systems are the primary components of the system. Once a lifetime mission profile for the vehicle is established, R/M predictions can be expediently accomplished and any R/M drivers toward unacceptable availability and/or support costs can be identified and eliminated or mitigated prior to production commitments.

At this point in the preliminary design, R/M predictions can only be estimated based on best practical engineering judgement and experience. Assuming that the mileage accumulated during a typical year performing rescue and firefighting operations is less than 500 miles, it would appear that an overall vehicle MTBF of 1000 hours is achievable. Although a somewhat optimistic value, this number was achieved by comparisions of similar military and commercial hybrid operational vehicles and utilization rates.

ACRONYMS USED

LACV-30	Lighter, Air Cushion Vehicle, 30 Ton	MPWS	Mobile Protected Weapon System
LCAC	Landing Craft, Air Cushion	MTBF	Mean-Time-Between-Failure
RCM	Reliability Centered Maintenance	R/M	Reliability and Maintainability
LVT(X)	Landing Vehicle, Tracked - Experimental	NDI	Non Development Item



$\lambda_{TOTAL} = \sum_{i=1}^{5} \lambda_i = 0.003515$ failures/hr

$MTBF = 1/\lambda_{TOT} = 285$ hrs

△1 BASED ON ASSESSMENT OF BELL RELIABILITY PREDICTIONS FOR LVT(X) (Rpt 7615-950003),

△2 AVCO, NPRD-1, Based on PARTS COUNT ANALYSIS FOR ACTUATORS, VALVES, LINES & FITTINGS.

Figure 12-2. Reliability Block Diagram - Marine Drive Train

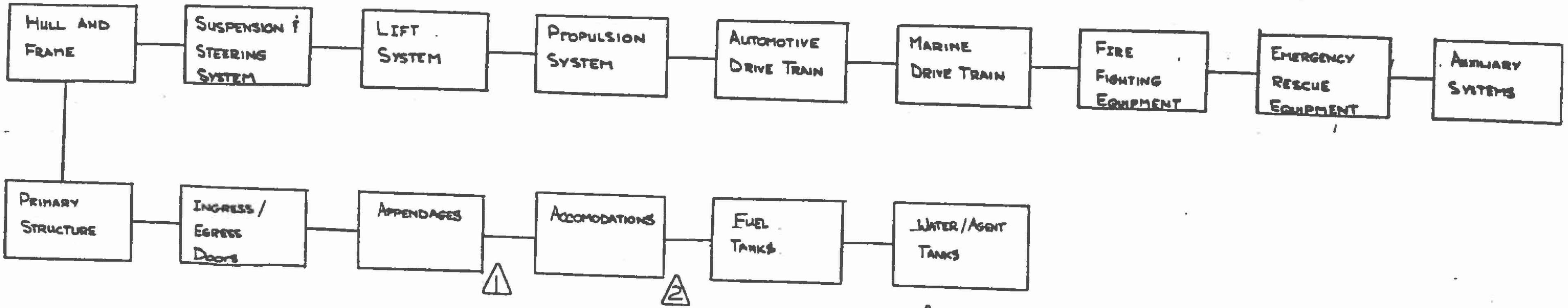


Figure 12-3. Reliability Block Diagram - Hull and Frame

△1 Assumed to include handrails, ladders, walkways/platforms & grills.

△2 Assumed to include driver's seat, storage racks/ compartmen for OEM/ Tool storage & triage area equipment/accomodat

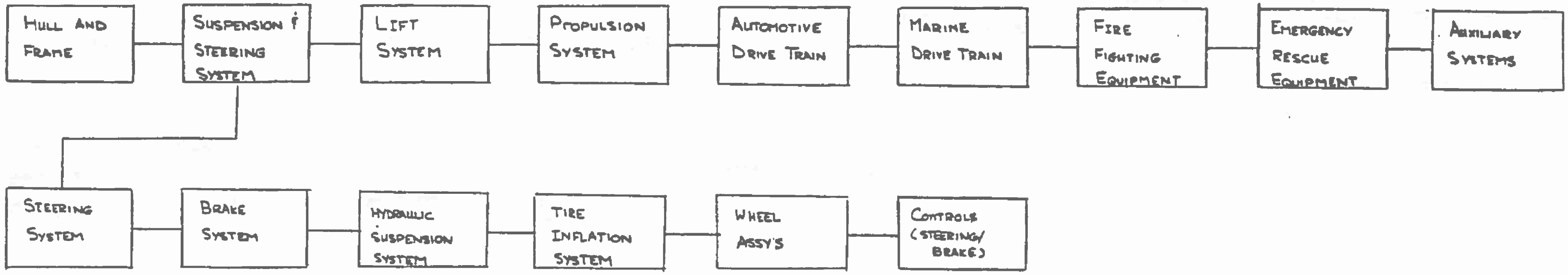


Figure 12-4. Reliability Block Diagram - Suspension and Steering System

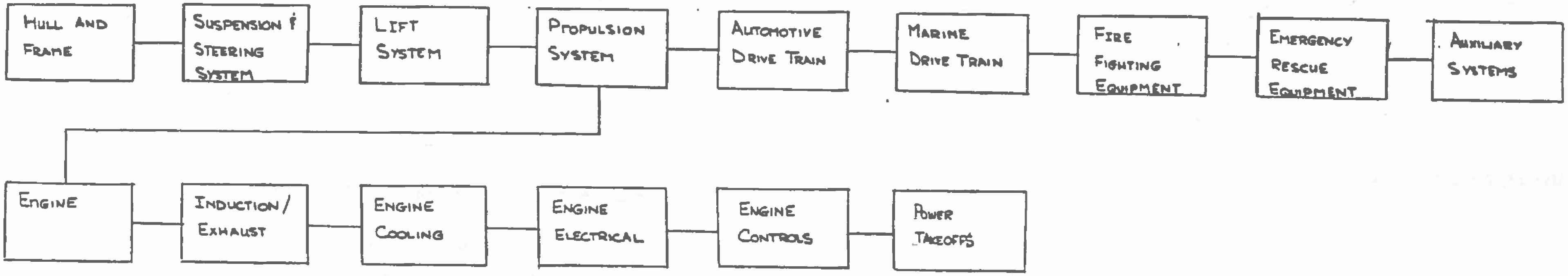


Figure 12-5. Reliability Block Diagram - Propulsion System

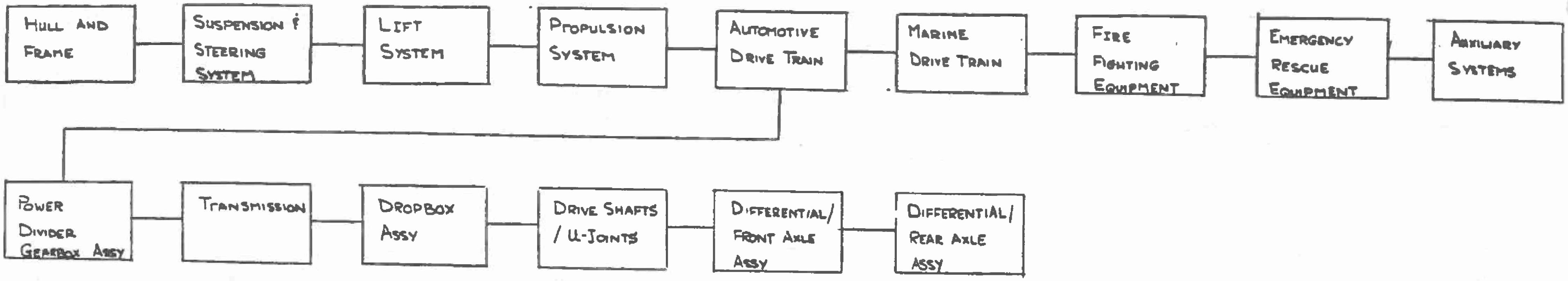


Figure 12-6. Reliability Block Diagram - Automotive Drive Train

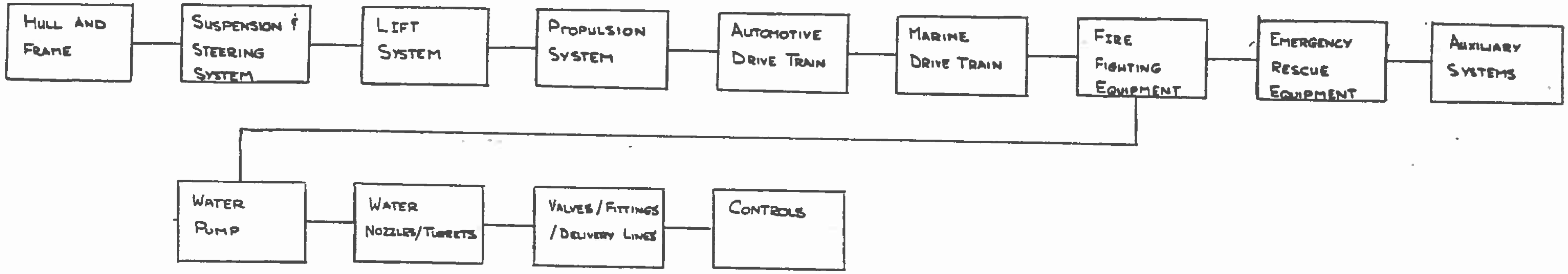


Figure 12-7. Reliability Block Diagram - Fire Fighting Equipment

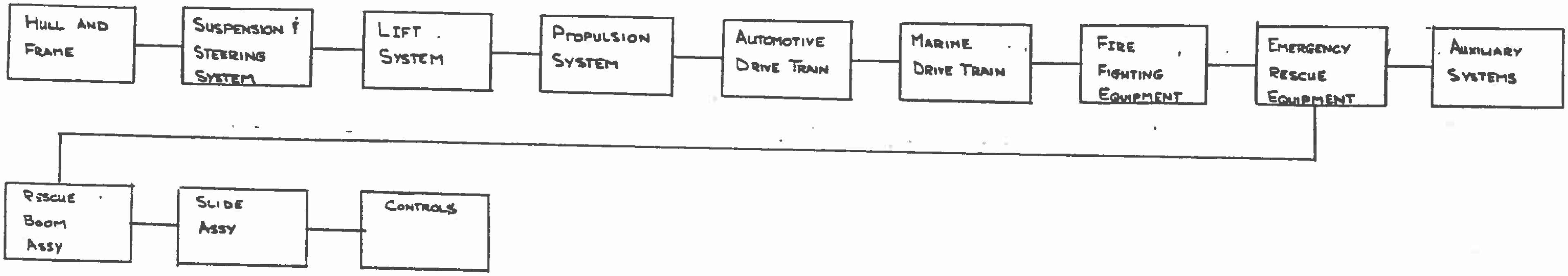


Figure 12-8. Reliability Block Diagram - Emergency Rescue Equipment

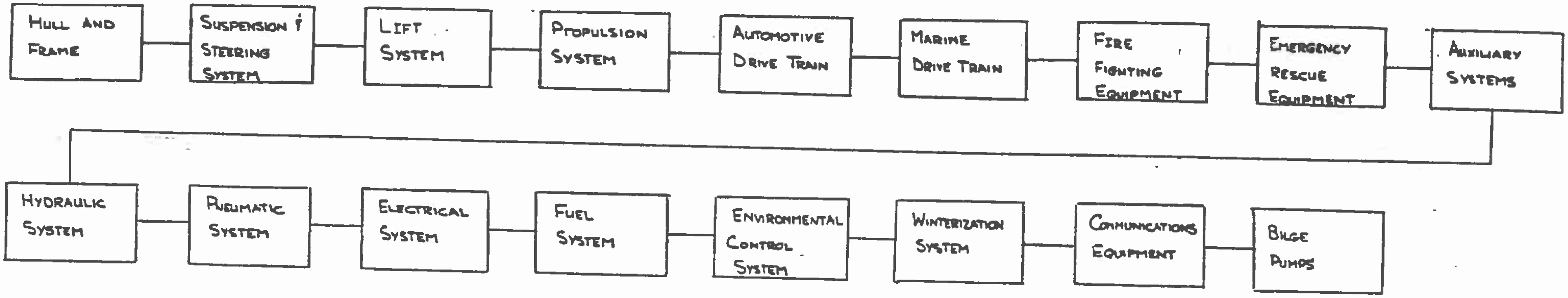


Figure 12-9. Reliability Block Diagram - Auxiliary Systems

13.0 PRELIMINARY ACCRV PRODUCTION COST ESTIMATE, SCHEDULE, AND TRADEOFF

13.1 Cost Estimate

The estimate for production of 500 ACCRV's was derived from preliminary design information. This information, which included sketches and a weight statement, were used to identify major items to be priced. Further discussions were held with cognizant engineers to assist in obtaining comparisons to other similar vehicle components, which have previously been quoted or purchased.

The hourly rates were estimated on the basis of production at a typical truck manufacturing facility. All the necessary production hours and material to fabricate and assemble the vehicle have been included. Support labor such as Quality, Engineering Liaison, Manufacturing Support and Program Management have been estimated. The rates and material were escalated to reflect a period of time representing the second quarter of 1987.

The basic fabrication estimate was made using dollars and hours per pound for the structure based on past experience from a similarly constructed vehicle at an offsite out-of-state location. The balance of the estimate was based on R.O.M. component quotes obtained, extractions from other recent vehicle estimates, and judgmental estimates.

The estimate was made for the first 50 and projected on a 90% improvement curve for the remaining quantity in lots of 50 as follows:

Lot	Lot Size	Unit Cost
1	50	$773,000
2	50	625,000
3	50	578,000
4	50	548,000
5	50	529,000
6	50	512,000
7	50	499,000
8	50	489,000
9	50	479,000
10	50	471,000
	500	

13.2 Production Schedule

The ACCRV Production Schedule is shown in Figure 13-1. The subsystems are arranged in the projected sequence of manufacture and assembly.

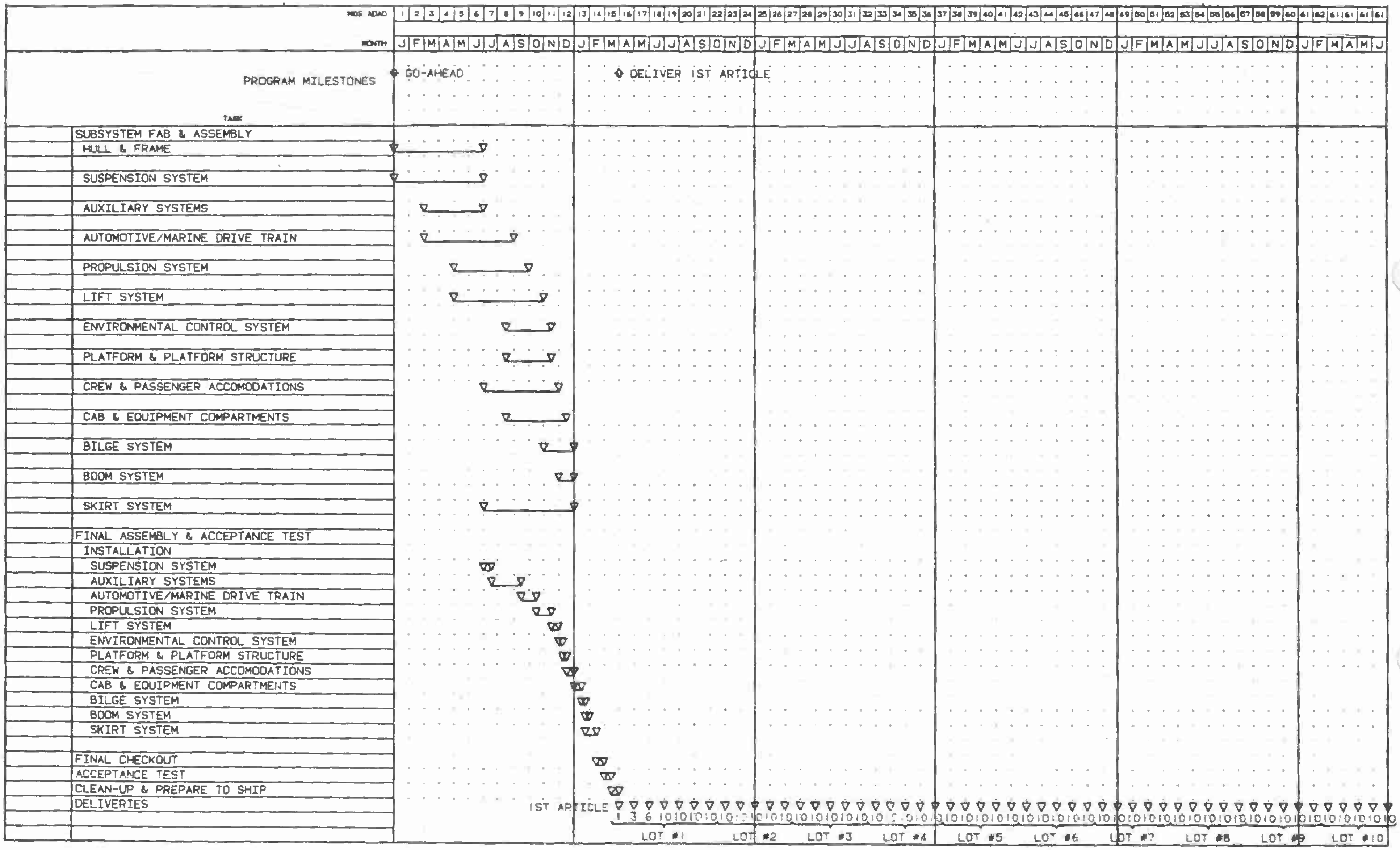


Figure 13-1. ACCRV Production Schedule

It is anticipated that the vehicle hull and frame will be assembled in the horizontal position, right side up. The unit will then be turned on its side to receive all of the hardware to be assembled to the bottom of the vehicle. This includes the auxiliary, automotive/marine drive train, propulsion, lift and environmental control systems. The vehicle will then be placed in an upright position on its wheels to install the platform and platform structure or decking. The balance of the equipment will be mounted on this deck in the sequence shown and the skirt assemblies will be mounted on the sides.

It should be noted that a go-ahead will be required during the Full Scale Development Program to purchase long lead raw materials such as honeycomb aluminum and to fabricate rate (duplicate) tooling.

The schedule protrays lots of 50 as required in the Statement of Work. The rate of production (10 per month) was selected as being reasonable. If it is deemed necessary to change the rate, the quantity of tooling can be increased or decreased as desired.

13.3 Tradeoffs to Reduce Cost and Weight

As discussed previously, all aspects of the ACCRV design were directed towards minimizing weight so that the 30,000 lbs gross vehicle weight limit would not be exceeded. Several possible trade off items have been identified to try and simplify the ACCRV system and reduce the vehicle's total cost. In addition to material changes, structural redesign of the boom, removal of the triage area, and relocation of the paddle track have been selected as the items which will have the greatest impact on cost and weight.

To keep weight to a minimum, a readily available aluminum honeycomb sandwich panel was selected for hull construction. Although the honeycomb is very strong for its light weight, it is also expensive and minor fenderbender accidents may be hard and expensive to repair. The hull structural frame is estimated to weigh approximately 2,100 lbs if fabricated from the honeycomb. However, by utilizing 3/16 inch aluminum planking, the hull cost could be significantly reduced. Unfortunately the hull frame weight would increase to 4,500-5,000 lbs, which would require weight reductions in other areas.

Another possible trade off to reduce cost and weight is redesign of the rescue boom. Since there is no off-the-shelf boom available to meet the ACCRV weight and performance requirements, a company that specializes in composites has been selected to design the boom. Redesign of the boom to a two section design, with no kinks or telescoping parts, could make production cheaper. Additionally, using constant cross section boom sections would be even cheaper, although heavier. Another possibility is the replacement of the boom with a hydraulically actuated extension ladder. These are readily available but they do not have the same dexterity as an articulated boom.

As a possibility for reducing weight and allowing more space for the internal subsystems, it should be stated that the enclosed triage area could be eliminated. Stretchers could then be placed on the side cushion platforms, which would be down for operations on air cushion over adverse terrain. If the cushion is already in the retracted position, then other rescue vehicles will be there. An additional benefit of removing the triage area, and its associated equipment, is a savings in vehicle cost.

A final change, which is not actually a trade off, is relocation of the paddle track from between the rear wheels to the middle of the ACCRV. Moving the paddle tracks close to the center of gravity (cg) will improve stability and maneuverability. Also, moving the tracks away from the rear drive mechanism will increase the Reliability and Maintainability (R&M) of the system and allow the use of hydrostatic drive. Although it has not been determined yet, the paddle track will be able to use lighter rubber or aluminum tracks. Since both track types have their good and bad points, a decision on which type of track system to use should be further investigated for application on the ACCRV.

No specific values have been assigned to predict possible cost or weight savings if the above discussed changes are implemented. It remains a possible task for Full Scale Development.

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ABBREVIATIONS - ACRONYMS

ACCRV - Air Cushion Crash Rescue Vehicle
STO - Standard Operating
STD - Standard
NDI - Nondevelopment Item
R&M - Reliability and Maintainability
MTBF - Meantime between Failures
ACV - Air Cushion Vehicle
ROM - Rough Order of Magnitude
RPM - Revolutions Per Minute
c.g. - Center of Gravity
NASTRAN - NASA Structural Analysis
FSD - Full Scale Development
CBR - (California) Bearing Ratio
LACV-30 - Lighter, Air Cushion, Vehicle - 30 Ton Payload
LCAC - Landing Craft, Air Cushion
LVT(X) - Landing Vehicle Tracked, Experimental
VEHDYN - Vehicle Dynamics Computer Program
BDR - Bomb Damaged Runways
GPM - Gallons Per Minute
GVW - Gross Vehicle Weight
HET - Heavy Equipment Trailer
DDA - Detroit Diesel Allison
SHCP - Naval Ship Hull Characterization Program
CRF - Crash Rescue Firefighting
ACET - Air Cushion Equipment Transporter
CP - Center of Pressure
HSI - Heave Stability Index
SOW - Statement of Work
RCM - Reliability Centered Maintenance