

PROPORTIONAL RATE AUTOPILOT SYSTEMS

Presented to

NATIONAL MARINE ELECTRONICS ASSOCIATION

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by

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Chief Engineer

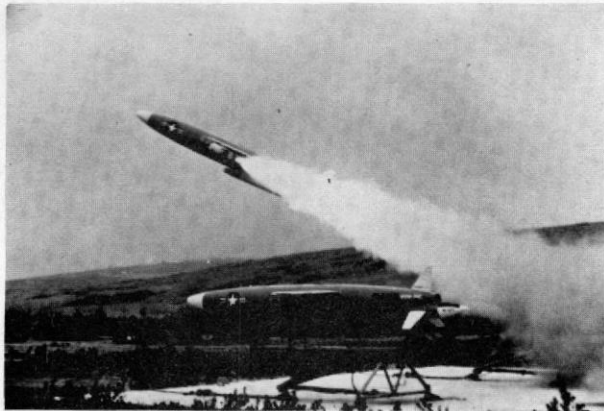


**Cetec Benmar**

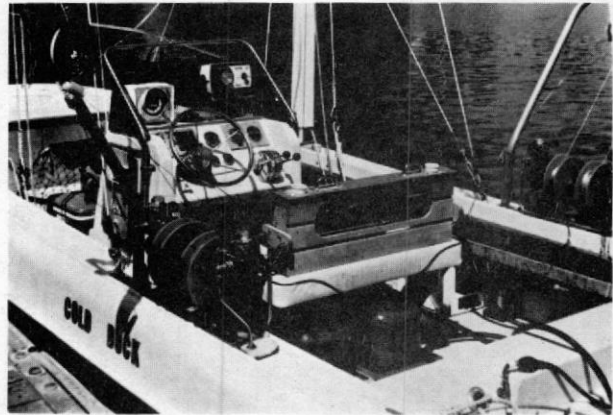
Marine division of Cetec Corporation

3000 West Warner Avenue, Santa Ana, Ca 92704





CHUCKAR II  
Aerial Target  
500 Knots



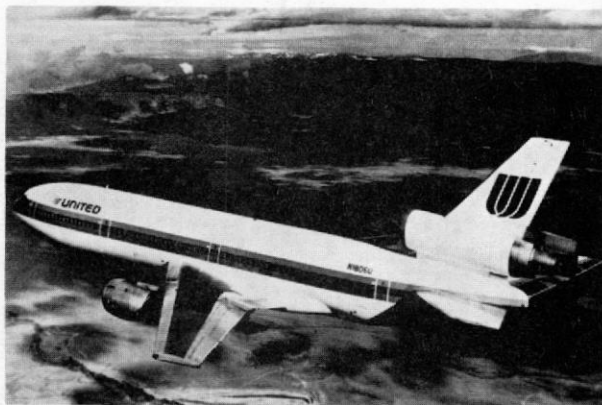
COLD DUCK Boston Whaler  
Salmon Fishing Boat  
20 Feet - 40 Knots



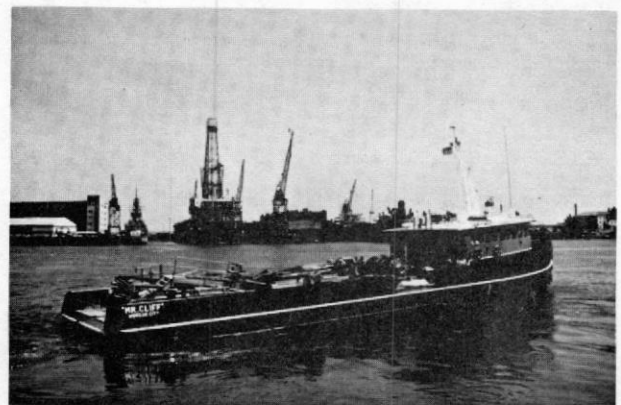
SNARK Intercontinental Guided  
Missile  
69 Feet - 500 Knots



MR ED Thompson Trawler  
Snapper Boat  
65 Feet - 23 Knots



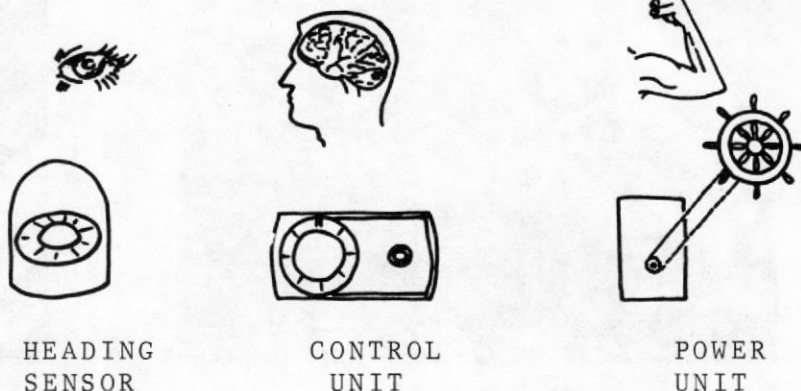
UNITED AIRLINES DC-10  
Commercial Aircraft  
179 Feet - 500 Knots



MR CLIFF Steel Hull & Pilot House  
Oil Island Work Boat  
120 Feet - 14 Knots

The size, speed and media of these vehicles are as varied as their missions. What do they all have in common? They are all steered in at least one degree of freedom by a "Proportional Rate Autopilot".

Every autopilot consists of three major black boxes: 1) a heading sensor, 2) a Control Unit, and 3) a Power Unit. How each one of these boxes are mechanized, the degree of simplicity and sophistication is as varied as the vehicles shown above.



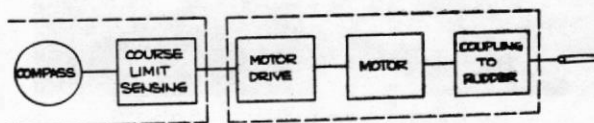
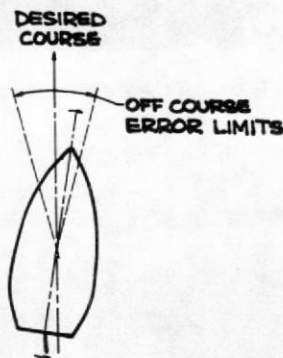
THE THREE MAJOR COMPONENTS OF AN AUTOPILOT

In order to understand what "Proportional Rate Autopilot" really means one should take a brief look at the history of the development of marine autopilots.

THE FIRST GENERATION

The hunting autopilot developed in the 1930's is generally considered the original marine autopilot design. It uses a compass which contains a switch or "whisker" contact. This switch closure is used to control the steering motor. The compass and contacts detect whether the boat is to port or starboard of the proper heading.

The motor is driven in one direction with the contacts closed and in the other direction when they are open. This causes the boat to continuously cycle back and forth across the correct heading. Hence, the descriptive name "hunting autopilot". The amount of "zig-zag" will vary from boat to boat. While the hunting autopilot is simple in concept, the constant zig-zag course does not contribute to fuel economy.



HUNTING SYSTEM



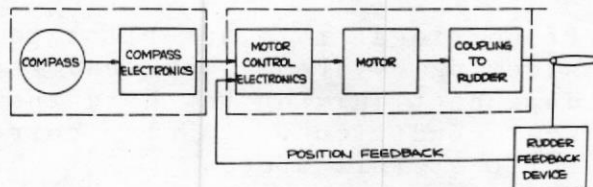
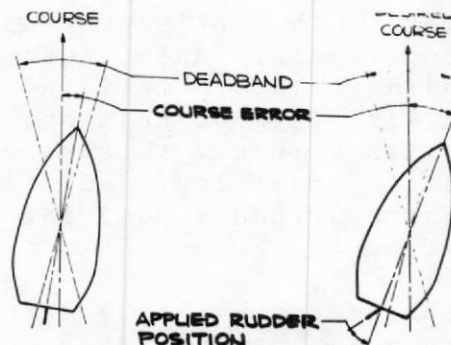
The constant cycling of the hunting autopilot also causes high autopilot power consumption and excessive wear on the steering system and the autopilot. In spite of these first generation disadvantages, hunting autopilots are still produced and sold today to those who wish a simple, easy-to-understand and repair autopilot.

THE SECOND GENERATION

The second generation of autopilots was developed in the 1940's. In the proportional deadband pilot a heading error deadband in which the helm is inactive was introduced into the system. When the heading error exceeds the deadband the helm is then moved in the appropriate direction, an amount proportional to the heading error. As the boat is brought back to within the heading error deadband, the helm is brought back amidships and is again inactive. Thus the helm is driven only when necessary to bring the boat back within the on-course deadband.

This lowers the autopilot power consumption and, of course, eliminates the continual zig-zag. The disadvantage of this type of system is that the boat still may "wander" within the deadband, thus not maintaining as tight a course as desirable. On many autopilots of this type, the deadband is adjustable and may be minimized according to boat characteristics and sea conditions. Also a proportional deadband autopilot requires some sort of rudder feedback device to tell the autopilot where it has moved the rudder. This further complicates the pilot and its installation and, of course, lowers the reliability.

Up until the introduction of the third generation of autopilots in 1975, the vast majority of marine autopilots were of the proportional deadband type.



**PROPORTIONAL DEADBAND (POSITION) SYSTEM**

**AN AUTOPILOT WHICH CONTAINS A DEADBAND AROUND THE DESIRED HEADING AND WHICH OUTSIDE THE DEADBAND APPLIES A RUDDER POSITION PROPORTIONAL TO THE OFF COURSE ERROR**

THE THIRD GENERATION

In 1975 the third generation of marine autopilots was born. The "Proportional Rate Marine Autopilot System" was not a new birth however. It was rather a resurrection.

Proportional rate systems have been used for over 30 years on aircraft, missile and space vehicle control systems where increased response, reliability, and performance are essential.

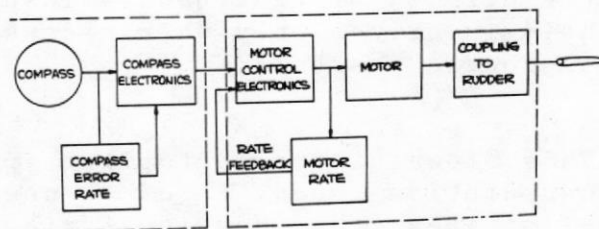
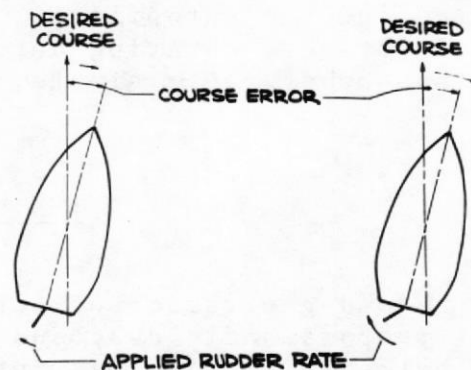
A "Proportional Rate Autopilot" is one in which a rudder rate or speed (rather than a position) is applied to the rudder, which is proportional to the heading error and the rate of change of heading error. The primary input to a "Proportional Rate Autopilot" is heading rate. There is no deadband and it is not hunting. Since it applies a rudder rate rather than a rudder position, it does not require a rudder position feedback device.

With the removal of a deadband, the autopilot no longer wanders within a course deadband but now steers a tight prescribed course, taking action with the presence of even a minute course error. The amount of action, however, remains small when the course error rate is small; that is, a very low helm correction rate is applied when the course error rate is low.

Proportional rate autopilot power consumption, therefore, is low and steering system wear and tear is low. Power consumption is dependent only on how hard the pilot must work due to the prevailing sea conditions. Helm correction is smooth, not jerking back and forth at full speed.

HOW DO YOU DETERMINE SYSTEM TYPE?

Now after having defined the three basic types of marine autopilots, how do you tell whether an autopilot is one type or the other? The easiest way should be to look on an advertisement or a data sheet; the next best to look at the hardware and its controls. Unfortunately, engineering people and marketing people don't read the same books. I have even suspected that marketing people use dictionaries with blank pages to be filled in as the need arises or when they hear unfamiliar words.



**PROPORTIONAL RATE SYSTEM**  
 AN AUTOPILOT WHICH APPLIES A  
 RUDDER RATE PROPORTIONAL TO  
 THE OFF COURSE ERROR

With this in mind, lets define a few terms that are frequently used or misused.

### DEFINITIONS

PROPORTIONAL Having the same or a constant ratio - being in proportion. Has no meaning until you say proportional to what.

RATE Speed, either linear or angular. How fast a boat turns or a rudder turns. For technical types, the first time derivative of position.

COURSE ERROR RATE (ANTICIPATION - COUNTER RUDDER) The rate at which a boat is turning or being driven off (or on) course. This is the primary input to a "Proportional Rate Autopilot".

VARIABLE RATE (POWER UNIT) A Power Unit in which the output shaft rate can be varied from zero to its maximum rate in proportion to the applied input (and the rate of change of the input).

These terms appear quite often on data sheets sometimes in a descriptive way and sometimes very much out of context.

The next best way to determine autopilot type is by looking at the hardware and its external controls. While this is not a surefire method, there are several clues which can separate a "Proportional Rate Sytem" from a "Proportional Deadband (Position) System".

### ABSENCE OF EXTERNAL CONTROLS

A "Proportional Rate System" inherently replaces many external controls with internal automatic features.



**DEADBAND CONTROL** The most obvious control missing on a "Proportional Rate Autopilot" is the deadband (most often called sensitivity, sometimes called null, yaw, sheering or weather) control. A "Proportional Rate Autopilot" has no deadband, thus no control for it.

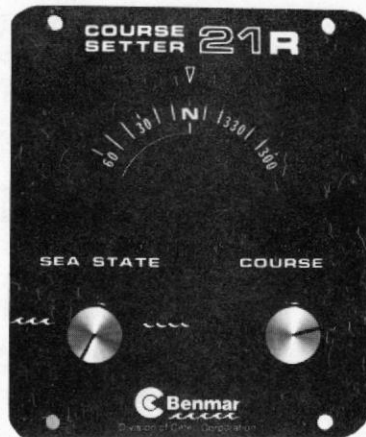
**RUDDER TRIM CONTROL** A "Proportional Rate Autopilot" inherently has automatic trim, thus no trim control. (This will be discussed later in detail.) While automatic trim is added in some "Proportional Deadband Systems", many employ an external rudder trim (sometimes called trim, weather helm or permanent helm) control.

**RUDDER RATIO OR RUDDER CONTROL** This is a gain control which changes the proportionality constant of applied rudder angle to boat off course error in a proportional deadband system. Since boat response changes as the boat's forward speed changes, on most boats it is necessary to change the autopilot gain to maintain acceptable performance. A corresponding control on a "Proportional Rate Autopilot" would change the applied rudder rate to off course error proportionality constant. However, due to the increased response and range of response of a rate system, this is very seldom necessary. External gain controls appear on less than 10% of the "Proportional Rate Autopilots".

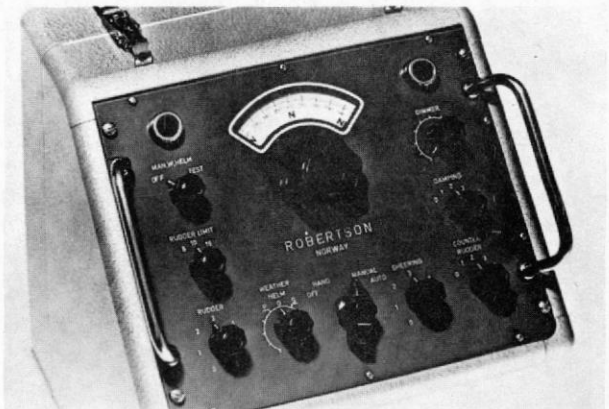
**COUNTER RUDDER CONTROL** This control adjusts the proportionality constant between course error rate and amount of applied counter rudder on those "Proportional Deadband Autopilots" which utilize course error rate.



Wesmar AP900 Control Unit  
(Proportional Deadband)



Benmar CS21R Control Unit  
(Proportional Rate)



Robertson AP6 Control Unit  
(Proportional Deadband)

SEA STATE CONTROL This control is a variable filter which filters wave action inputs in a "Proportional Rate Autopilot" when one wishes to slow down the helm response in a heavy sea. This control does not change the DC gain nor change the course resolution. It only filters fast inputs.

ADVANTAGES AND DISADVANTAGES

Now why have a "Proportional Rate Autopilot" rather than any other type? What are the advantages and disadvantages?

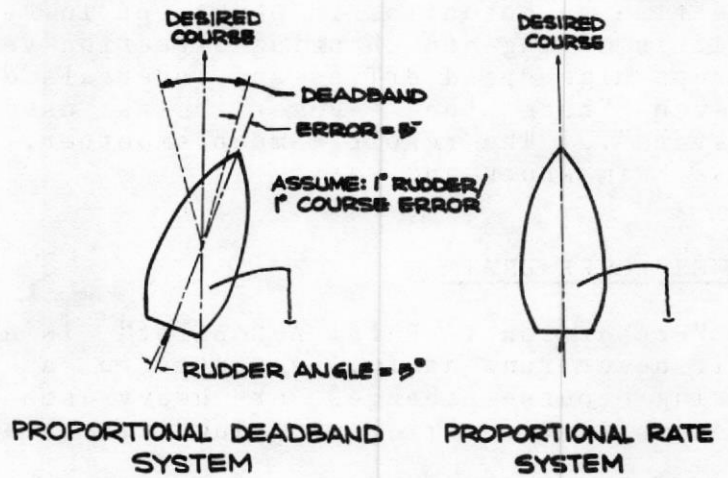
RESPONSE

"Proportional Rate Autopilots" have been utilized for years in situations where added response and smooth operation are mandatory. A "Proportional Rate Autopilot" always utilizes course error rate. This results in faster response and therefore optimum following sea performance. It steers a boat much like an experienced helmsman, anticipating what the boat heading will be as it swings and applying counter rudder to check course overshoots as it brings the boat on to course. Course Error Rate is sometimes utilized as an added feature in "Proportional Deadband Autopilots".

The extended response of a "Proportional Rate System" minimizes the need for continual autopilot gain changes as a boat changes speed, course and sea conditions. It maintains responsive steering on vessels from 18 to 180 feet at speeds from 5 to 45 knots.

AUTOMATIC TRIM

In any proportional deadband system, the rudder position is directly proportional to off course error (after the deadband has been exceeded). Therefore, when a side load such as nets or loss of one engine pushes the boat off course, a rudder offset can not occur without a course error. That is, the autopilot can only bring the boat part way back on course. In a "Proportional Rate Autopilot", the rudder rate is proportional to off course error without regard to its position. The rudder rate is only zero when the boat is exactly on course and holding that course. Thus, the rudder will continue to be driven to whatever offset position is required to bring the boat exactly on course.



**AUTOMATIC TRIM AND SIDE LOADS**



Automatic trim circuitry is sometimes added to "Proportional Deadband Autopilots" as an added feature. It is inherent in a "Proportional Rate Autopilot".

#### MINIMUM CONTROLS, MAXIMUM AUTOMATIC FEATURES

In the same way that more modern technology such as phase locked loops replaces manual crystal channelizing in a VHF, a "Proportional Rate Autopilot" replaces many manual external controls with automatic internal features.

#### NO RUDDER FEEDBACK DEVICE

Electromechanical components are among the most unreliable electronic components in existence. A rudder position feedback device is just such an animal. In addition to this, on a hydraulically steered boat, the device must live back near the rudder in a wet, salty, high vibration area. On a "Proportional Rate Autopilot", a rudder feedback device is not used. Rate feedback is electronically mechanized internally in the Power Unit. Hydraulic creep which necessitates a feedback device right at the rudder in a "Proportional Deadband (Position) System" is of no consequence in a "Proportional Rate System".

#### VARIABLE RATE POWER UNIT

In order to have a "Proportional Rate Autopilot", one must have a variable rate Power Unit. That is, one in which the output shaft speed (and thus the rudder rate) is proportional to the input voltage and the rate of change of the input voltage. How is this an advantage? When the course error is small, which is the majority of the time an autopilot is ON except in very heavy seas, the Power Unit is moving and changing direction very slowly in contrast to the abrupt high speed drives and reversals characteristic of the relay driven "bang bang" Power Units used in "Proportional Deadband Systems". The result - much smoother, quieter operation and much less helm shock and wear.

#### LOWER POWER DRAIN

A "Proportional Rate Autopilot" is a "demand" system. The Power Unit never runs at full speed as in a "bang bang" system except during course changes or heavy sea conditions. Thus the power consumption is very low during light sea conditions.

#### FREEDOM FROM NON-LINEAR AND DEAD RUDDER EFFECTS

Many boats exhibit non-linear and/or dead rudder effects. That is, a boat may be very responsive to the first few degrees of applied rudder while the next 40 degrees increase the turn rate by a nearly negligible amount. Conversely on some boats, the first 5 degrees or

so of rudder cause no boat response at all while the next 40 degrees causes a reasonable response. With a "Proportional Deadband (Position) System", the applied rudder position is linearly proportional to course error. When the rudder response is not linear the autopilot is not responsive, hard to stabilize, and in an extreme case may be impossible to stabilize. In this case it may be necessary to re-design and linearize the rudder response in order to obtain satisfactory autopilot operation.

In a "Proportional Rate System" the rudder rate, not position, is proportional to course error and course error rate. The rudder is driven thru or into a non-linear region to whatever position is necessary to bring the course error and thus the rudder rate to zero irregardless of ineffective or high gain rudder positions.

#### THE FOURTH GENERATION

Until only recently marine autopilot design has lagged the rest of the technical world by about 20 years. The gap is closing and fourth generation design should just about make us current. What will it be like? It's on drawing boards now but one can only speculate on the final hardware. If its to satisfy the needs of everyone, commercial and pleasure boaters, dealers and installers, if probaably will have the following features:

Proportional Rate Control System

Microprocessor Based Design

The ability to communicate with other shipboard electronic equipment (such as Loran C).

The ability to easily add many programmed options.



**Cetec Benmar**

Marine division of Cetec Corporation

3000 West Warner Avenue, Santa Ana, Ca 92704

THE AUTOPILOT INTERFACE TO  
MARINE HYDRAULIC SYSTEMS

Presented to

NATIONAL MARINE ELECTRONICS ASSOCIATION

Miami, Florida

February 20, 1979

by

ED POLLARD

Chief Engineer



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3000 West Warner Avenue, Santa Ana, Ca 92704

The purpose of this seminar is to educate the marine electronics dealer/installer in the selection and installation of an autopilot in a boat with a hydraulic steering system.

Before attempting an installation, a dealer must first have a good knowledge of marine hydraulic systems. There are approximately 20 major marine hydraulic steering system manufacturers throughout the world, each one doing his own thing in his own way. However, there are only three basic types of marine hydraulic steering systems. Figure 1 shows a basic hydraulic steering system.

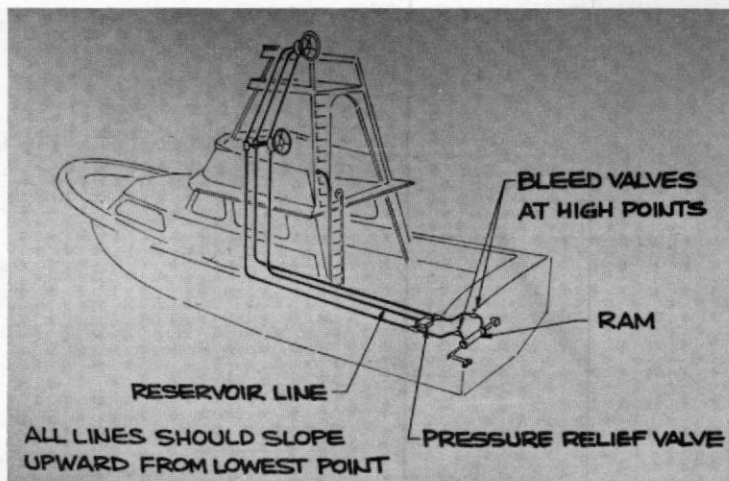


Figure 1. Basic Hydraulic Steering System.

MARINE HYDRAULIC STEERING SYSTEMS

A basic two line manual marine hydraulic steering system is shown in Figure 2.

SYSTEM COMPONENTS

HELM PUMP Almost all manual helm pumps sold today are piston type pumps. Helm pump size is defined by its displacement. Pump displacement is the amount of fluid which is pumped in one revolution of the helm. Manual pump displacements range from 3 cubic inches per revolution to 18 cubic inches per revolution. Some have an external adjustment to alter the pump displacement.

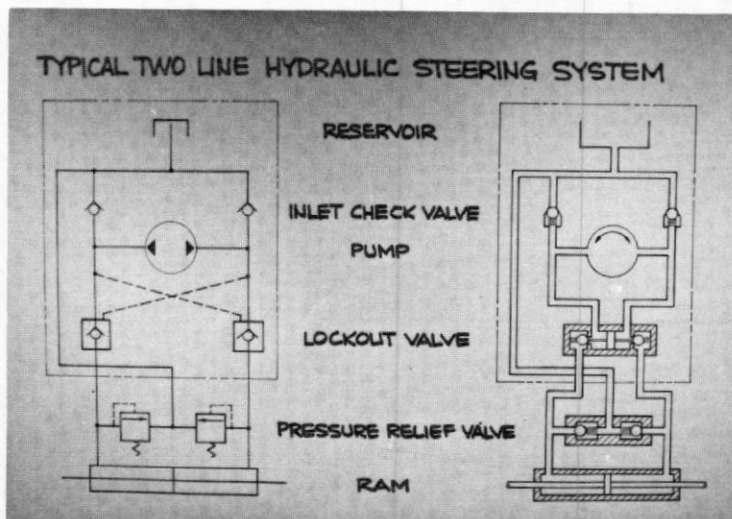


Figure 2. Basic Two Line Manual System.



RESERVOIR Every system must contain a hydraulic fluid reservoir. Most helm pumps contain the reservoir inside the pump housing which is vented to the atmosphere. However, some system reservoirs are external to the pump and may be pressurized to about 30 PSI above atmosphere.

INLET CHECK VALVES The inlet check valves in the helm pump are one way valves. These valves are the means by which oil may be pulled from the reservoir into the pump.

PRESSURE RELIEF VALVES Pressure relief valves prevent damaging pressure buildup when there is excessive rudder torque or when thermal expansion causes internal pressure rise. Pressure relief valves may be found in various locations in the system. Some helm pumps have built in relief valves within the pump. Other manufacturers install pressure relief valves back near the rams. Some manufacturers do not utilize pressure relief valves in their systems.

LOCKOUT VALVE Without a lockout valve, most manual helm pumps will motor if pressure is applied to one of the pump connections. To prevent this, a lockout valve (often called a lock valve, shuttle valve or pilot operated shuttle valve) is utilized to lock out the helm pump when it is not being used. Many helm pump manufacturers build lockout valves into their helm pumps.

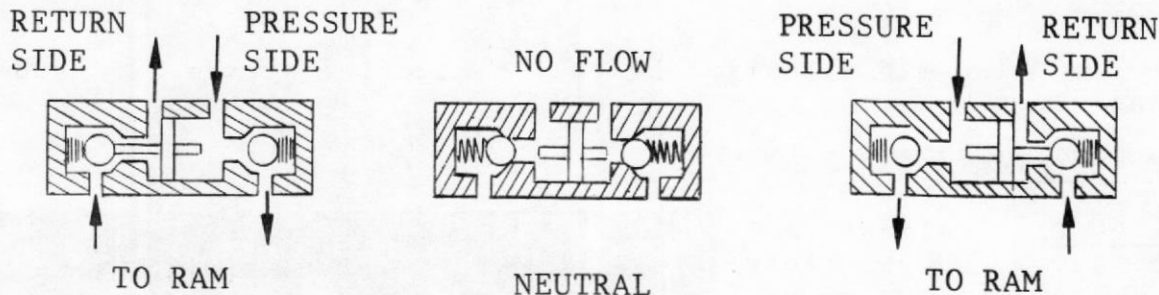


Figure 3. Lockout Valve.

RAM OR STEERING CYLINDER The ram in a hydraulic steering system is the component that does all the work and actually moves the rudder. The size (volume) of the ram (along with the displacement of the helm pump) determines the mechanical advantage of the steering system - how easy or how hard it is to steer. Any autopilot must be matched to the ram size for optimum autopilot performance. Figure 4 shows both a balanced and unbalanced ram.



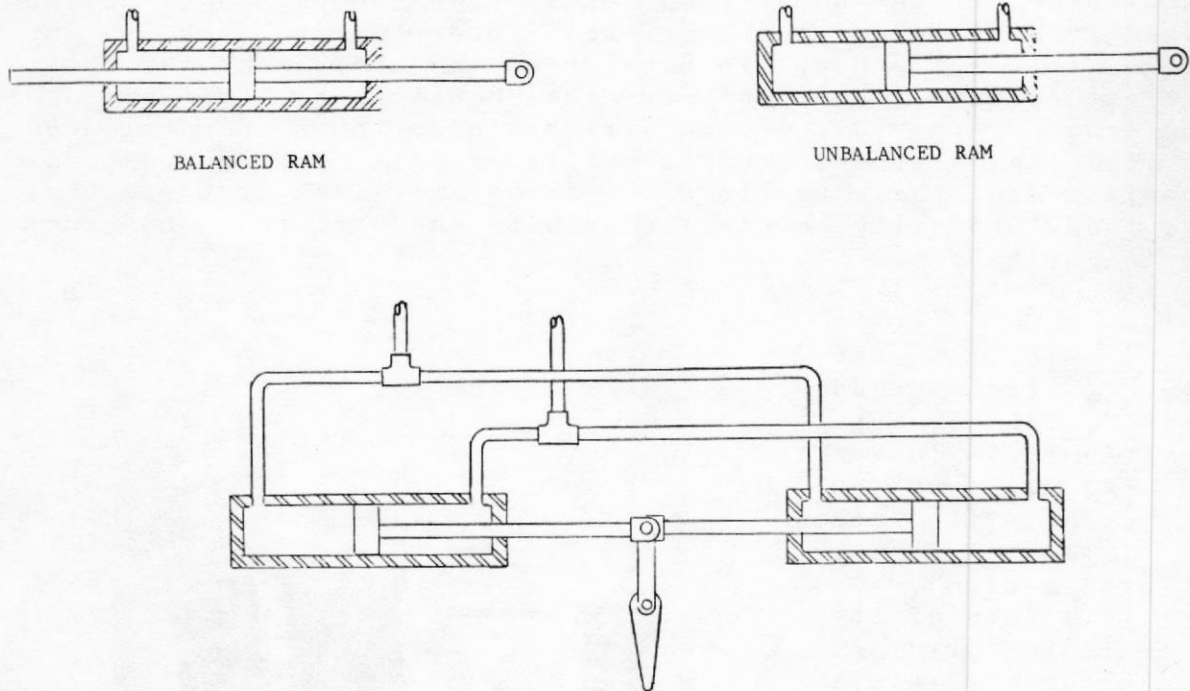
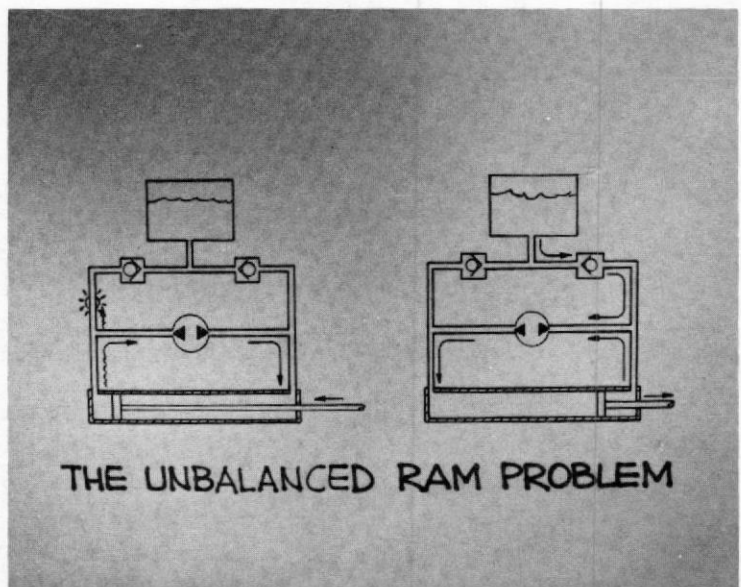


Figure 4. Balanced and Unbalanced Rams.

Balanced and unbalanced rams refer to the fluid volume occupying the ram when the piston is fully at one end of the ram and again when it is at the other end as in Figure 5. As can be seen in the unbalanced ram, the rod displaces fluid on one side of the piston but not on the other. Thus, it may require more than 20% more fluid to move the piston in one direction than in the other. That is, a different amount of fluid comes out than goes in.



THE UNBALANCED RAM PROBLEM

Figure 5. Unbalanced Ram Problem.

Most hydraulic rams in marine steering systems are balanced. However, an installer must know ahead of time whether the ram is balanced or unbalanced. Many autopilots will not function in certain systems with unbalanced rams. Unbalanced rams may be recognized by a different number of helm turns lock to lock in one direction than the other. An unbalanced ram also lacks the shaft and seal extending out one end of the housing. Obviously, a balanced ram of the same volume will be longer than an unbalanced ram due to the extended shaft. While single unbalanced rams occasionally find their way into all types and sizes of boats they are used today primarily on smaller in/outs where there is no room for the longer balanced rams.

HYDRAULIC FLUID The most commonly recommended hydraulic fluids are Type A Automatic Transmission Fluid (ATF), Dexron SAE-10 Turbon Oil, and Shell Tellus 25/30. These are medium viscosity oils. Some of the newer small boat hydraulic steering systems require special (low viscosity) fluid to function efficiently. These light oil systems use very low viscosity hydraulic fluids such as Shell Tellus 10 and 15.

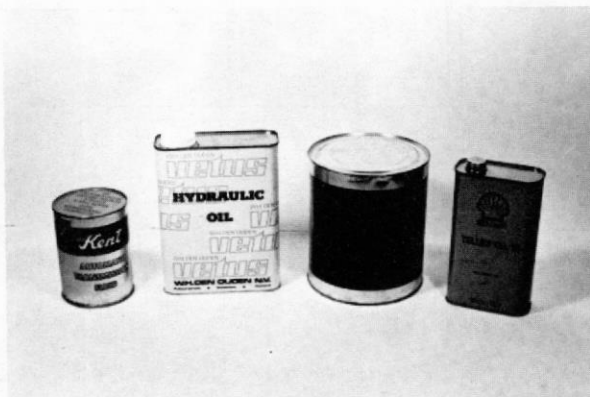


Figure 6. Hydraulic Fluid.

The dealer/installer must know what type of fluid is used in the hydraulic system prior to selecting an autopilot Power Unit. IF LIGHT OIL IS USED IN THE SYSTEM THE DEALER MUST INSURE THAT THE POWER UNIT HE SELECTS IS DESIGNED TO BE USED IN LIGHT OIL SYSTEMS. The autopilot Power Unit must be matched to the hydraulic system. Never change the fluid to match the Power Unit.

### SYSTEM TYPES

While there are many different manufacturers of hydraulic boat steering systems all doing the same thing in a little different way, we only need to be concerned with one major system difference to properly install an autopilot Power Unit. The three major system types are defined as two line, three line and four line systems and are shown in Figures 7 thru 12. The difference between these systems is not in the number of hydraulic lines used. They all use two output lines to the ram. The difference is in the fluid flow in the systems.

TWO LINE SYSTEMS Figure 7 shows typical two line manual hydraulic systems. In the two line system, fluid flows in both directions in the output lines depending on which way the helm is rotated.

Figure 7 also shows a Hynautic two line system with its external pressurized reservoir and pressure relief valve which is mounted back near the ram. This system is often mistaken for a three line system due to the pressure relief valve and the third. (reservoir) line. This is a two line system. The third line carries fluid only when overpressure bypass occurs. The third line is sometimes smaller than the output lines in this system.

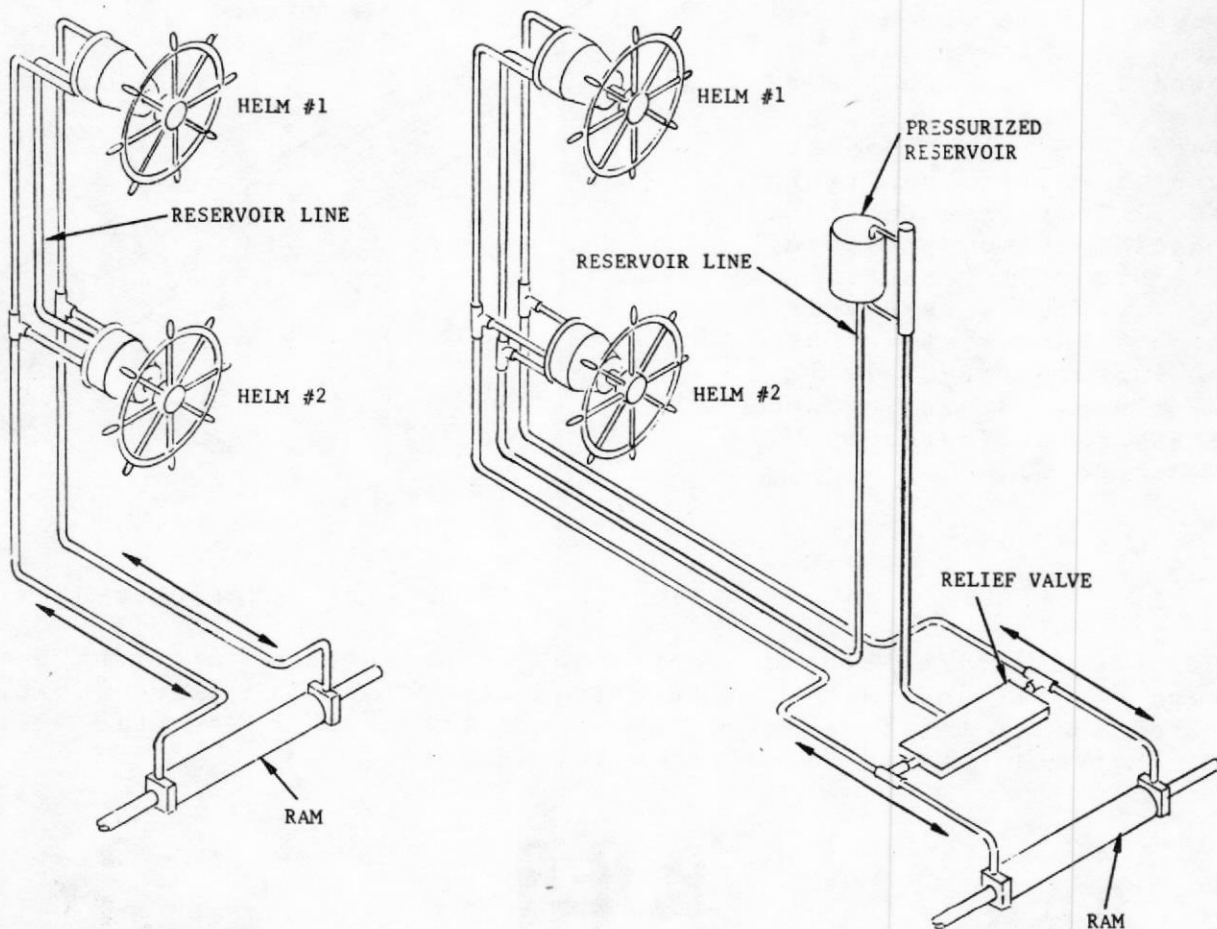


Figure 7. Two Line Systems.

THREE LINE SYSTEMS Figure 8 shows a typical three line system. IN THE THREE LINE SYSTEM, FLUID FLOWS ONLY IN ONE DIRECTION; OUT OF THE PUMP TOWARD THE RAM IN THE TWO OUTPUT LINES. All of the fluid returns to the pump via the reservoir (return) line. A system of valves mounted close to the ram steers the returning fluid from the low pressure side of the ram into the third line. The third line is the same size as the output lines since it continuously carries all the fluid flow. It is frequently a plastic (low pressure) line since it returns to the vented reservoir. Three line systems are manufactured by Teleflex (Capilano), Hynautic and Vetus (distributed by W. H. Denouden).

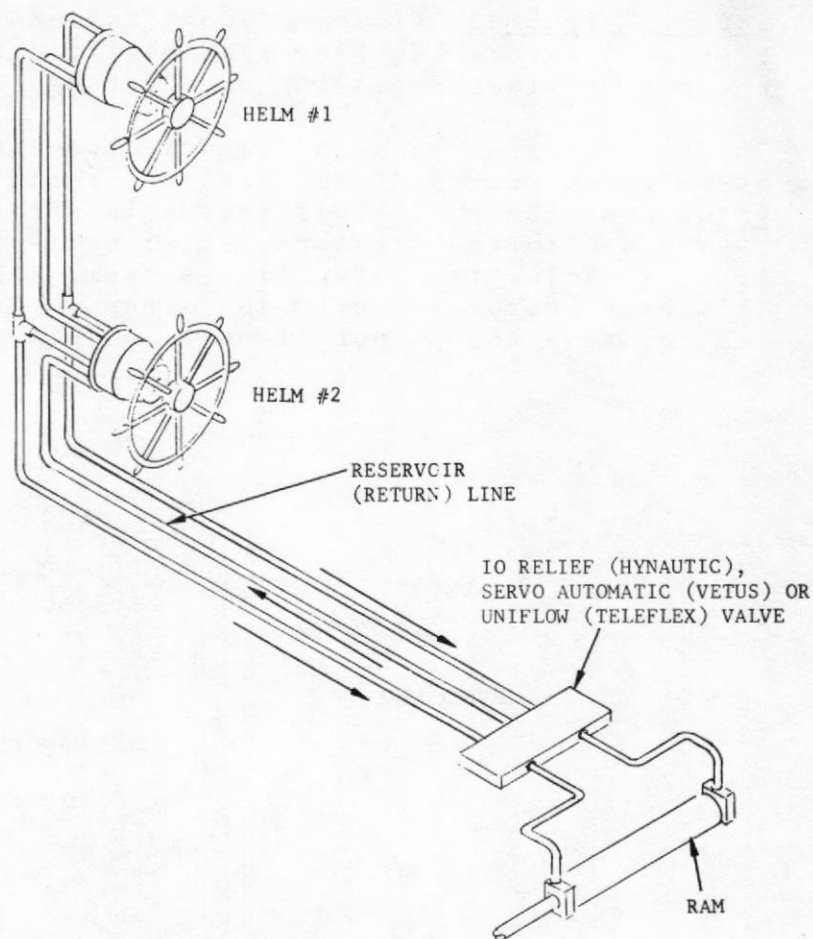


Figure 8. Three Line Steering System.

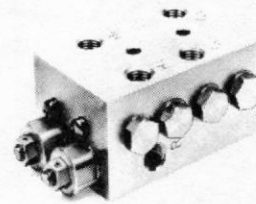
The steering valve blocks supplied by these three manufacturers are shown in Figure 9. The steering valve block is called "Uniflow Valve" in a Teleflex system, "IO Relief Valve" in a Hynautic system and "Servo Automatic Valve" in a Vetus system.



VETUS  
SERVO AUTOMATIC  
VALVE



TELEFLEX  
UNIFLOW VALVE  
(MODEL 50)



HYNAUTIC  
IO RELIEF VALVE  
(MSV 22 OR 24)

Figure 9. Steering Valve Blocks.



The steering valve block "causes" a system to be a three line system. A Teleflex Uniflow Valve is shown in Figure 10.

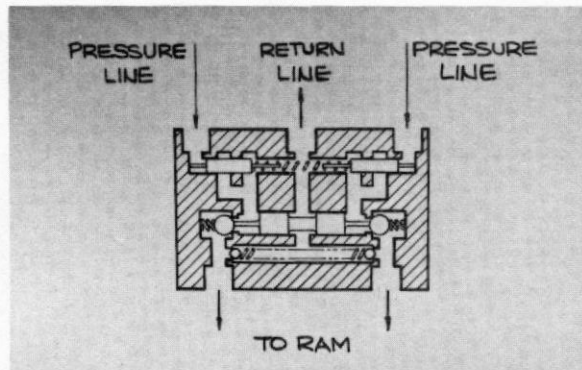


Figure 10. Teleflex Uniflow Valve.

Two of the most useful aspects of this device are: 1) It allows the use of an unbalanced ram. Opening the low pressure side into the reservoir permits more or less fluid to leave the pump than is returned without causing excess pressure in the system. 2) Due to the "one way" nature of fluid flow the system is self purging and easy to bleed initially.

Not all Teleflex, Hynautic or Vetus systems are three line systems - only those which utilize a steering valve block. In general, a straight pressure relief valve on a two line system has only three ports. The steering valve block which steers fluid into the return line in a three line system has at least five ports (a Vetus two station Servo Automatic Valve has seven ports).

FOUR LINE SYSTEMS Figures 11 and 12 show two forms of four line systems. Four line systems are power steering systems. In all four line systems, the pump runs continuously (in one direction only). In some systems, it is driven by an electric motor; in others, it is belt driven off the boats main engine. Helm torque is quite low (usually less than 30 inch pounds) while power handling capability is quite high. These systems are seldom used on boats under 50 feet in length. The boat may still be steered manually if the pump is not running at the expense of higher helm torque and/or more turns lock to lock.

Figure 11 shows a typical popular system using a Char Lynn "Orbitrol" helm unit. Fluid flow thru the pump circuit is in one direction, as shown, continuously circulating thru the helm unit(s). When the helm unit is rotated, fluid is steered from the pump circuit into the appropriate output line to the ram. Fluid flow is therefore in both directions in the two output lines.



Frequently, on larger boats with power steering systems, the helm unit and wheel will be replaced with a solenoid operated "Jogger Valve". A jogger stick in the pilot house operates a valve which steers the full pump fluid flow in one direction or the other to operate the ram.

FLUID FLOW:

HELM NOT TURNING - A TO B.

HELM TURNING ONE DIRECTION -

A TO D TO RAM, C TO B FROM RAM.

HELM TURNING OPPOSITE DIRECTION -

A TO C TO RAM, D TO B FROM RAM.

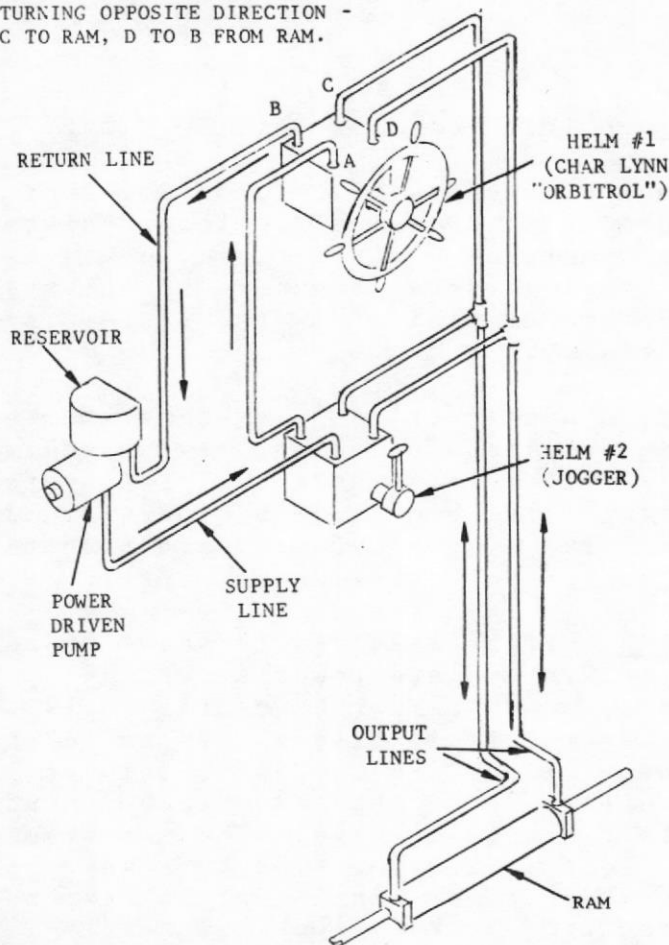


Figure 11. Four Line Steering System (Char Lynn "Orbitrol" and "Jogger" Type.)

Figure 12 shows a Hynautic "follow up" power steering system. In this system also, fluid flows continuously in one direction in the power driven pump circuit. When the helm unit shaft is rotated, fluid from the helm unit moves the small servo ram which then steers fluid from the power driven pump into the large ram, thus moving the rudder. The servo ram "follows up" stopping further fluid flow in the large cylinder until again commanded by the helm pump.

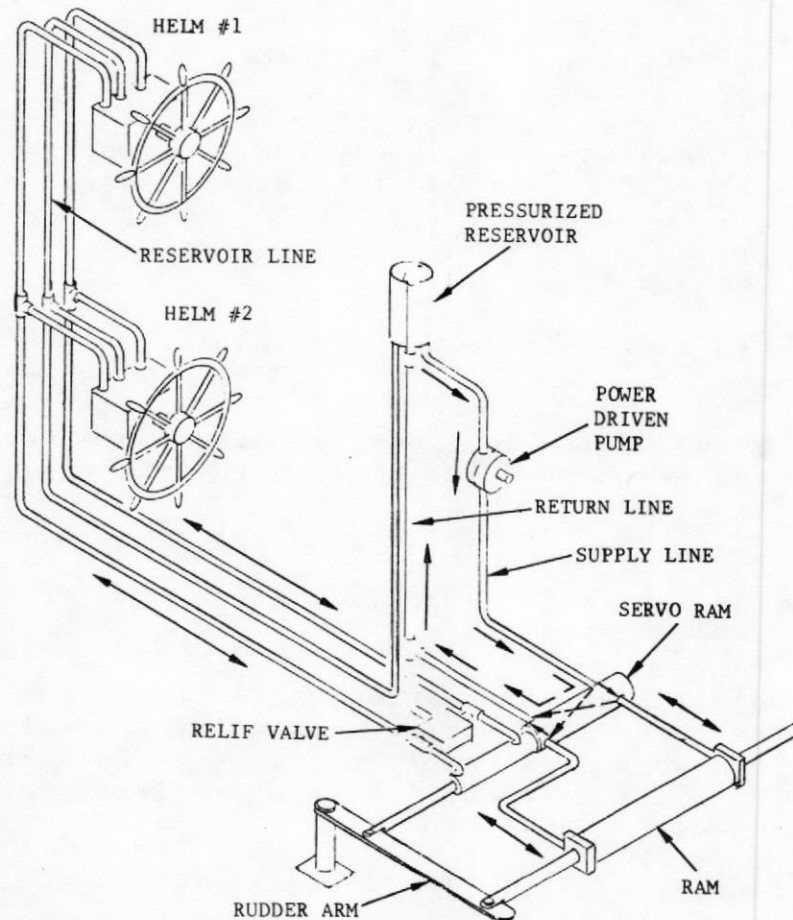


Figure 12. Four Line Steering System (Hynautic).

LIGHT OIL SYSTEMS About 1975, "light oil" marine steering systems began to appear. Today there are three manufacturers of light oil systems. The helm pumps for these three systems are shown below.



Figure 13. Light Oil Helms.

Light oil steering systems are beginning to appear in great abundance on boats from 18 foot in/outs to 36 foot power boats.

These systems are characterized by:

1. Small (1.7 to 2.0 cubic inches per revolution) economical helm pumps.
2. Plastic (nylon) hydraulic lines, although some boat manufacturers use copper tubing with these systems.
3. Small (6 to 10 cubic inches) economical rams.
4. The use of a light (low viscosity) oil.

The Hynautic and Wagner light oil systems are two line systems. The Teleflex is a three line system when a Uniflow valve is used and a two line system when it is not used. Most American and Canadian boats with Syten helms will have the Uniflow valve. Many European boats will not.

The light oil (lower viscosity) is used in these systems to minimize pressure drop in the smaller diameter tubing and to minimize helm unit "bumps" and stiffness.

The use of standard (medium viscosity) hydraulic fluid may seriously degrade light oil steering system performance. The medium viscosity fluids can cause helm stiffness and bumps or helm cogging as the helm is rotated. The nylon tubing may flex and pulsate more with higher viscosity fluids. USE ONLY THAT FLUID RECOMMENDED BY THE STEERING SYSTEM MANUFACTURER.

AUTOPILOT POWER UNIT SELECTION CRITERIA

There are five things to consider in selecting an autopilot Power Unit to match to a boat with a hydraulic steering system:

1. Installation type.
2. System volume (lock to lock slew time).
3. System pressure.
4. Fluid type.
5. System type.

INSTALLATION TYPE

Either a hydraulic Power Unit or a mechanical Power Unit interconnected to an existing hydraulic helm unit may be used on hydraulic systems. Figure 14 indicates a very clean, economical method to interconnect mechanical Power Units into hydraulic steering systems. As indicated, some hydraulic helm units even have stub shafts out the back of the hydraulic helm unit to facilitate connecting a more economical mechanical Power Unit into the system. One must remember that if the Power Unit is a proportional deadband type, a rudder feedback device must be connected back to the rudder.

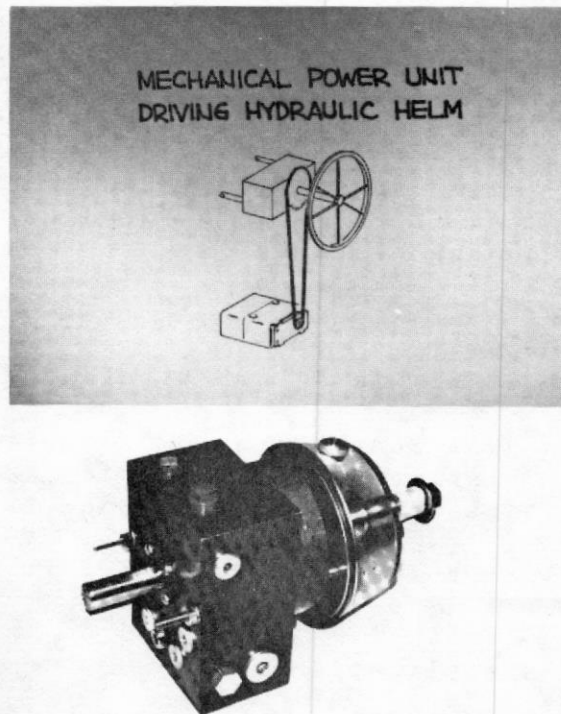


Figure 14. Hydraulic Helm and Mechanical Power Unit.

SYSTEM VOLUME

The hydraulic system volume is defined as the amount of fluid that must be pumped into the ram when the helm is rotated from lock to lock; i.e., the volume of fluid in the ram. The maximum flow rate of a hydraulic autopilot Power Unit must be matched to the system volume in order to get the proper autopilot lock to lock slew time.



There are two fairly simple methods to determine the system volume. The ram volume may be determined directly by taking the model number of the ram, looking on the data sheet of the hydraulic steering system, and determining the ram volume. Unfortunately, not all manufacturers place their model number on the rams and making outside dimensional measurements and calculating the ram volume is not an accurate indication of the inside volume of the ram. The second method to determine system volume is to determine the make and model number on the helm pump and also observe the number of turns lock to lock on the helm. The helm pump volume (amount of fluid pumped per revolution) may be determined from the manufacturer's data sheets. System volume can then be calculated by multiplying the helm pump volume by the number of turns lock to lock.

#### Example:

System Volume = Pump Displacement x Helm Turns (lock to lock)

Helm Pump: Vetus MT50

Displacement: 1.9 Cubic Inches Per Revolution

Measured Helm Turns Lock to Lock: 4.5 Revolutions

System Volume = 1.9 Cu. In. x 4.5 Rev. = 8.6 Cu. In.

Benmar's Application Note 26 lists all of the popular hydraulic system manufacturers, their helm pump and ram model numbers and volumes, to aid in these calculations.

A good rule of thumb is to select the autopilot Power Unit maximum flow rate such that the maximum lock to lock autopilot slew rate will

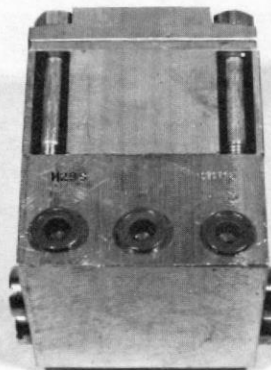


Figure 15. Ram and Pump Model Numbers.

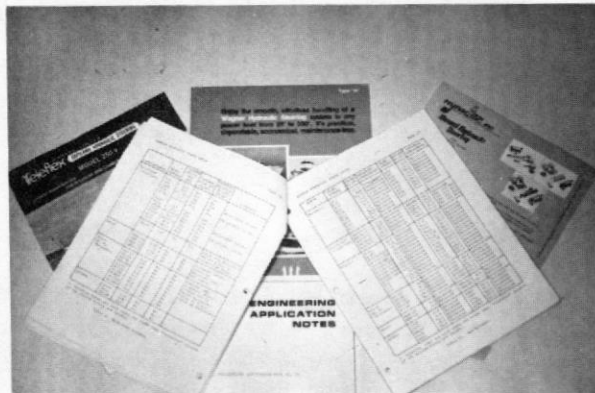


Figure 16. Data Sheets.



lie somewhere between 12 and 18 seconds. While this number is not critical, when the lock to lock slew rate is less than 12 seconds, the autopilot becomes more difficult to stabilize. As the lock to lock slew time increases beyond 20 seconds, the rudder response rate and thus, the autopilot response in a following sea is compromised. One should check with the particular autopilot manufacturer as to their specific recommendations regarding lock to lock slew time.

### SYSTEM PRESSURE

The autopilot Power Unit operating pressure rating must be higher than the nominal hydraulic steering system operating pressure. There is no simple way to determine hydraulic system operating pressure other than instrumenting the system. It's also very hard to apply a set of rules to determine the operating pressure, since there are so many parameters which affect operating pressure. However, there are some general observations that can be made:

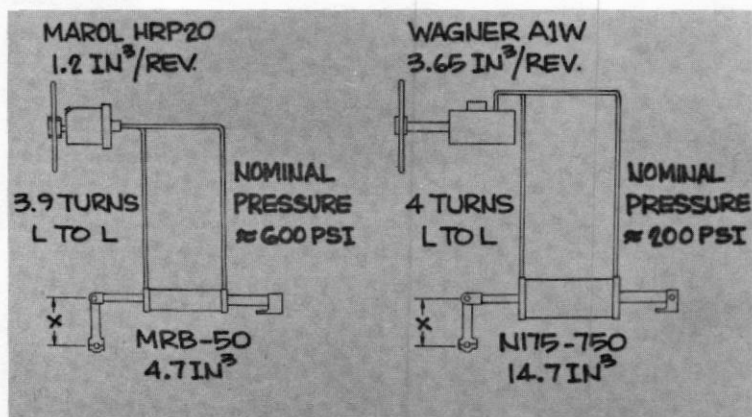
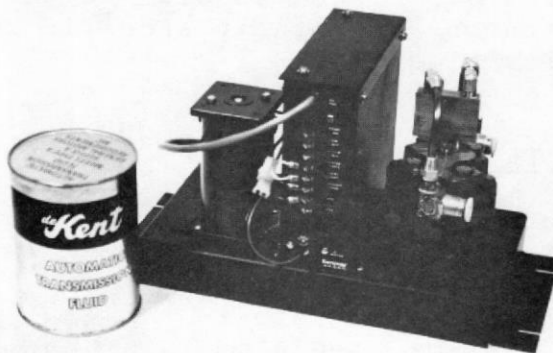


Figure 17. Volume vs Pressure.

1. The average nominal operating pressure on most domestic boats between 22 and 80 feet is between 100 and 200 PSI.
2. As rudder torque increases, ram volume must be increased to maintain the same internal system operating pressure.
3. With all else held the same, rudder torque is higher on single screw boats than on twin screw balanced rudder boats.
4. Rudder and hull design have a much greater effect on rudder torque than boat size and length.
5. Operating helm torque is not a good indication of internal system pressure. Figure 15 indicates two systems with identical mechanical advantage, i.e., for the same rudder torque the helm torque is identical. However, due to the system volumes, the internal operating system pressure is three times higher in one system than in the other.

HYDRAULIC FLUID

The majority of marine hydraulic steering systems use a medium viscosity fluid. As previously pointed out, the newer light oil systems use a much lower viscosity fluid. The hydraulic Power Unit must be designed to operate properly with the light oil in these systems. Check with the autopilot manufacturer to insure that the autopilot Power Unit will operate with light oil.

SYSTEM TYPE

In general, the same autopilot Power Unit will be used in a two line system or three line system providing that all the above criteria have been met. A four line system or power steering system requires a different approach. The various possibilities in four line systems are defined in the installation section.

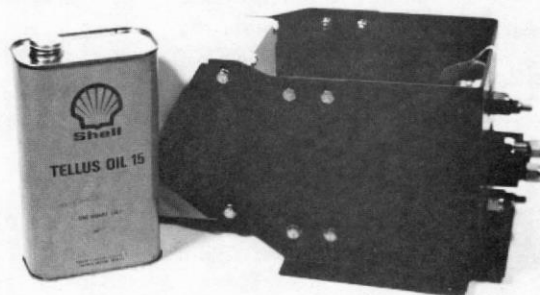


Figure 18. Power Unit vs Fluid

INSTALLING THE POWER UNIT

The Power Unit installation method is system type dependent. Figures 19 thru 21 indicate autopilot Power Unit installation methods on two line, three line and four line systems.

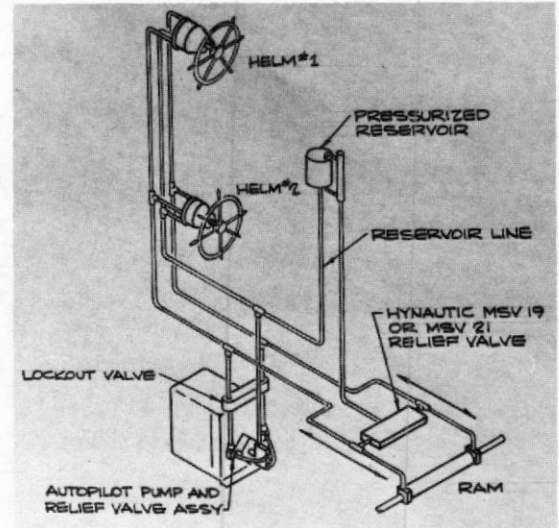
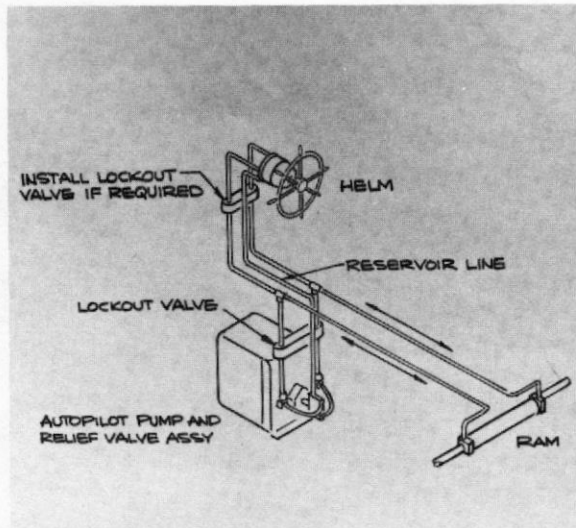


Figure 19. Two Line Installation.

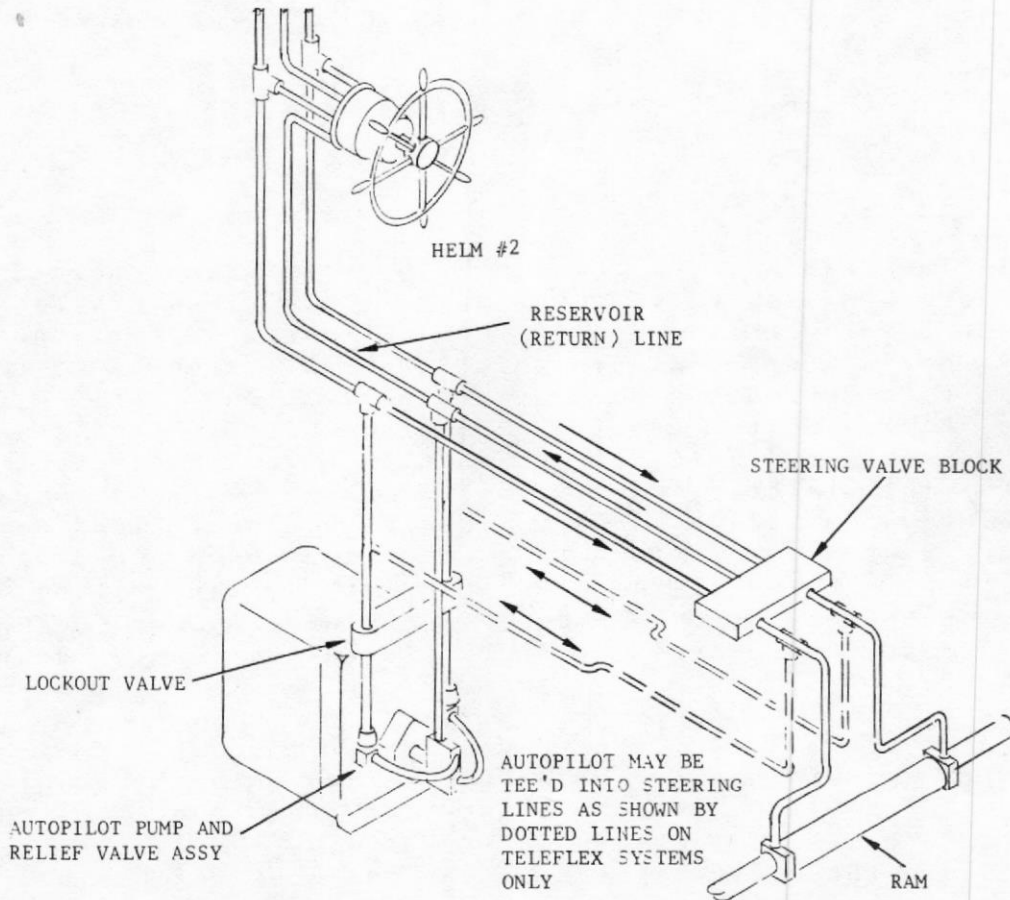


Figure 20. Three Line Installation.

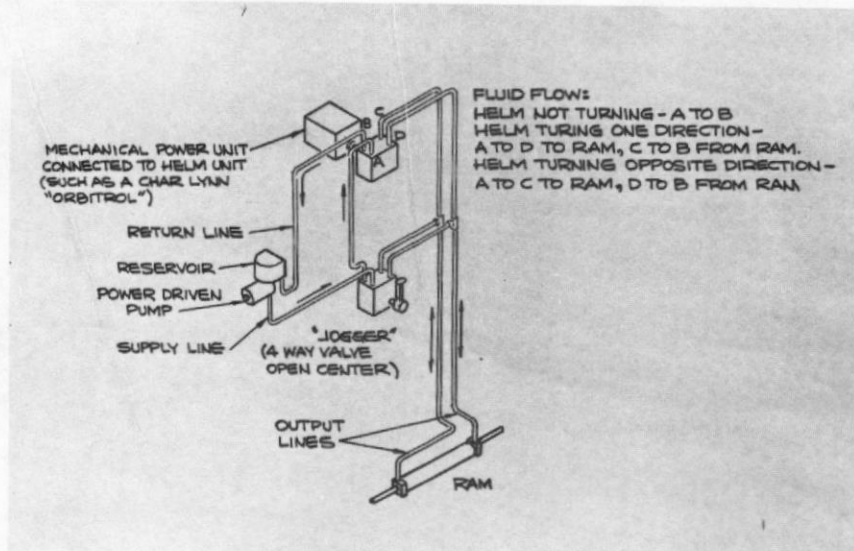


Figure 21. Four Line Installation.

A FEW DO'S AND DON'TS

The "BEST" location is near the ram. This minimizes operating line pressure drop. However, never sacrifice a clean dry Power Unit environment for lower line drop. The best position for the Power Unit may be in a dry engine room a few feet further away from the ram. Don't forget the third line (return). Almost all hydraulic autopilot Power Units require a third line to the reservoir. Wherever possible hydraulic lines should have a constant slope upwards to minimize trapped air. All new lines which are installed should be blown out and cleaned to insure that no filings or dirt enter the system. Teflon tape should never be used as a pipe thread sealer. Broken pieces of tape, dirt, copper filings in a hydraulic pump may become lodged in one of the many check valves and will almost surely cause a malfunction or seriously accelerate wear.

On unbalanced ram systems, the Power Unit must be designed to operate with an unbalanced ram, or a steering valve block, like the Capilano Uniflow Valve, must be installed, or the ram must be changed to a balanced ram. In other words, a two line system must be made into a three line system or the ram must be changed.



BLEEDING THE SYSTEM

Hydraulic system bleeding is the last step in installing a hydraulic Power Unit. It is also one of the most important steps. The presence of air in a hydraulic steering system does not only degrade the performance of the autopilot, but also the performance of the steering system.

The simplest most efficient way of removing air from the hydraulic system is to circulate air through the system in one direction until it enters the reservoir. Once it enters the reservoir, whether the reservoir is in the helm or a separate unit, the air rises to the surface and exhausts to the outside world. The ease with which this can be done is dependent on the system type, physical location of components, tubing layout and presence or absence of bleeding aids which allows the continual one way flow of fluid through the system. Reference should first be made to the boat hydraulic steering system manual for bleeding instructions on a specific system. REMEMBER THE OBJECT IS MOVE THE AIR FROM WHEREVER IT LIVES IN THE SYSTEM TO THE RESERVOIR.

While cranking the helm back and forth from lock to lock will eventually bleed a three line system, it will do essentially nothing in a two line system.

BLEEDING AIDS

There are several devices which can be used to more quickly and efficiently to bleed certain hydraulic steering systems. The hydraulic steering system manual is the best source of these bleeding aids. Figure 22 indicates two of these devices. Bleed screws in the Capilano Uniflow valve and pressure relief screws in the Hynautic pressure relief valve may be loosened to allow fluid a one way passage from the output line back through the return line to the reservoir.

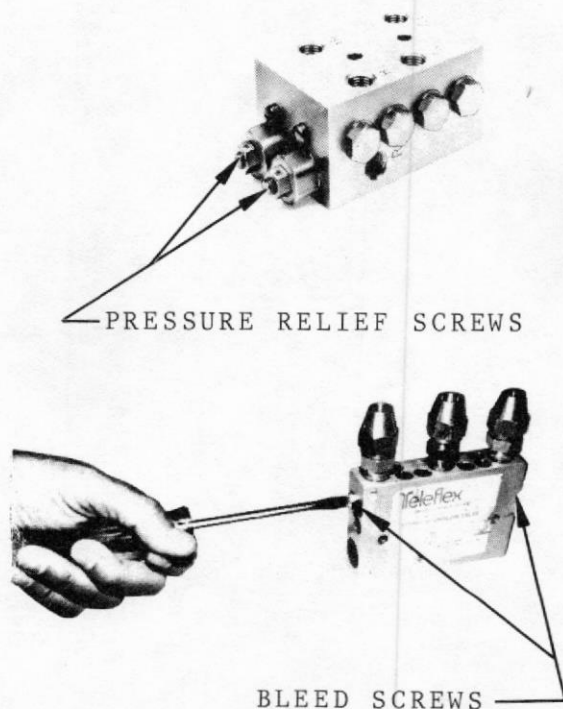


Figure 22. Bleeding Aids.

On many systems, especially two line systems, a very efficient way to bleed the autopilot Power Unit lines is to drive the autopilot Power Unit in full speed in one direction and, at the same time, turn the uppermost helm unit in the opposite direction at a rate which maintains the rudder at midships. This circulates the fluid and air through the autopilot, helm pump and reservoir, i.e., the object of bleeding. This works very well on those hard to bleed two line systems especially if the autopilot pump is located down near the ram far from the helm pump.

Since the fluid does not circulate in the ram, it is often necessary to bleed this part of the system by pressurizing and cracking high point fittings to allow the entrapped air to escape. Some rams contain bleed screws at either end of the ram which may be used for this purpose. A two line system should be given a final purge and fluid level check at least 8 hours after the initial bleeding. This allows any small bubbles or foam to form larger bubbles which may be more easily bleed off. A three line system should not require any further bleeding since the one way nature of fluid flow is self purging in normal operation.