MINISTAB SYSTEM DESCRIPTION

Quote From Grampaw Pettibone: "When you are flying a helicopter with an AFCS, you're not flying the helicopter you are flying the AFCS! The sooner you learn that, the sooner you'll stop making your crew sick!"

General Description

The MINISTAB system was designed and fabricated by Sfena Corporation, located in Grand Prairie, TX, to provide basic IMC flight capability for the TH-57 in the form of an Automatic Flight Control System (AFCS). The MINISTAB system is designed to be a three-axis transparent flight control system. In the pitch and roll axes it provides rate damping, attitude retention, and incorporates force trim features. Yaw augmentation provides rate dampening and a relative heading hold. The pitch and roll augmentation of the system essentially function independently from yaw augmentation. Additionally, in the cruise flight regimen the system also provides an altitude hold function. The MINISTAB is designed to be a transparent AFCS, which means the control inputs of the system are not appear to the operator, and the operator can at anytime override the AFCS with cockpit flight control inputs. These types of AFCS inputs, in which the AFCS is making flight control inputs in the background without the knowledge of the operator is termed "inner-loop". In other words, the operator does not have to actively think about using the AFCS system while flying. Force trim is designed to provide the operator with artificial feel due to the hydraulic boosted design of the flight control system. The AFCS system uses series actuators that are installed in conjunction with the flight control hydraulic boost servos. As a result the MINISTAB inputs into the flight control system are a made in an "inner-loop" fashion, in that the MINISTAB inputs are not detectable to the operator in the cyclic, collective or yaw pedals. A flow diagram of the MINISTAB operation is presented in enclosure (1). The system consists of 3 computers (one for each control axis), 3 Trim Damp Units (TDU), an Air Data Computer, 3 actuators, actuator position indicator, MINISTAB controller, Junction Box, cyclic grip trim switches, and pedal trim micro-switches.

MINISTAB Controller

A control panel (figure 2) installed on the center console between the pilots is designed to allow operators to control the operation of the MINISTAB systems. The control panel incorporates the following functions:

- FT – Turns forces trim on and off.
- STAB – Turns the stabilization functions of the system on and off for all axes simultaneously.
- ALT – Engages the altitude hold function when above 40 KIAS.
- TEST – Activates two different test modes of the system
  - TEST 1 – Checks over all system continuity and indicator lights.
  - TEST 2 – Checks altitude hold circuitry and functions.

Actuator Position Indicators

Galvanometer gauges are installed below the pilot's flight instrument panel on the right side of the cockpit. There is one gauge for each of the MINISTAB actuators, and they are designed to indicate the relative position of the indicated actuator, are primarily designed to alert the operator of active functioning of the respective servo.

Computer

Each control axis of the helicopter has a corresponding AFCS computer associated with it, i.e. pitch, roll and yaw. Each computer incorporates circuitry in order to function in any axis allowing the computer to be interchangeable with the aircraft. Additionally, each computer incorporates a power module, an angular rate gyro designed to be sensitive to 0.01 deg/sec, and servo amplifier circuitry. As the computer rate gyro senses changes in angular velocity, the computer logic circuitry sends flight control command to the AFCS servos via the servo amplifier circuitry.

Force Trim

A force trim system allows the operator to "trim" the flight controls in a selected position, and then apply flight control inputs away from the set position against the force gradient springs. When control pressure is released the flight controls will return to their position set by the magnetic brake. This system provides "artificial feel" while flying with hydraulic boosted controls. This function is accomplished by a Trim Dampener Unit (TDU). Pitch, roll, and yaw each incorporate a TDU, but they are unique and not interchangeable. Additionally, certain functions of the force trim system and TDU are coupled with operations of the MINISTAB.

PITCH AND ROLL FORCE TRIM

Two TDUs are installed in the aircraft for the pitch and roll axes. Each TDU incorporates a magnetic brake, force gradient springs, viscous dampeners, and a Control Motion Detectors (CMD). The TDUs primarily provide "trim" functions for the flight controls. TDUs are not interchangeable. The TDU magnetic brake can be released for the cyclic by setting the "FT" button (figure 3) on the AFCS control to off, or by pressing Force Trim button on the cyclic. When the magnetic brake is disengaged, all forces from the force gradient springs are released and the cyclic will move freely without any external forces applied to them. Further, when the magnetic brake is disengaged cyclic inputs are viscously damped by means of an Eddy Current Damper, which is intended to prevent abrupt control inputs from occurring when the brake is released. The CMD engages simultaneously with the magnetic brake, and detects when the cyclic is displaced from its "trimmed" position, sending a signal to the AFCS computer of the corresponding axis. This signal is used by AFCS computer to control AFCS functions.

YAW FORCE TRIM

The Yaw TDU consists of a magnetic brake, force trim springs, and a pedal micro-switches. The yaw TDU is located in the avionics bay behind the aft seats, prior to yaw AFCS servo. There are two pedal micro-switches, one for each set of pedals. The yaw magnetic brake and force trim springs are released with the "FT" button the control panel, or when both cyclic pedals are pressed which activates a pedal micro-switch (similar to the cyclic force trim button). When the magnetic brake is disengaged, all forces from the force gradient springs are released and the pedals will move freely without any external forces applied to them. When the pedal micro-switch is engaged (no force trim) a signal is sent to the yaw AFCS computer.

Control Tube/Actuator Assemblies (Copy from NATOPS, and more added)

The actuators are electro-mechanical linear actuators installed in the cyclic control tubes for cyclic inputs, and within the tail boom for the yaw AFCS actuator (figure 3 and figure 4). The actuators are driven by internal DC permanent magnet motors. The actuators respond to signals from the servo amplifiers in the pitch and roll computers. These signals cause the actuator to move about a neutral point with a total movement of approximately 0.5 inch. Movements of the cyclic AFCS actuators are applied to the both cyclic hydraulic servo input valves. This allows the AFCS actuators to make flight control adjustments without feedback through the flight controls to the pilots. Both cyclic actuators always move simultaneously. They move in opposite directions for roll inputs and the same direction for pitch inputs. The yaw AFCS actuator is not hydraulically boosted, and is installed between the yaw pedals and the trail rotor. The inputs to the tail rotor from the AFCS also do not feedback to the pedals. If actuators are not working about their neutral positions, they may be re-centered by depressing the cyclic FORCE TRIM button momentarily. Each AFCS actuator incorporates an over-heat bypass switch, which will trip and take the actuator off line if there is an overheating problem or condition within the servo. When the actuator cools, the over-heat switch will reset and the actuator will function again as normal. When the MINISTAB system is off, the Junction Box automatically commands the actuators to center and the flight controls function as conventional controls.

Note

Since the yaw AFCS actuator is not hydraulically boosted it is prone to overheating, especially during hovering operations in high temperature environments. If suspected, verify a frozen indication on the actuator position gauge. The servo will re-engage automatically when cooled. The FCS YAW circuit breaker (OVHD, ESS 2) may be pulled to remove power to the yaw AFCS system to assist with cooling.

Junction Box

The Junction Box provides the main interconnection between the AFCS computers to allow the coordination of the AFCS command functions, and distributes power to the flight control system. Additionally, the Junction Box provides an output to activate the FCS warning light on the Caution Panel. When the MINISTAB system is off or fails, the Junction Box automatically commands the actuators to center after a 0.6 sec time delay, and the flight controls will function as conventional controls.

Air Data Computer (ADC)

The ADC is connected to the aircraft pitot–static system and provides airspeed and barometric altitude information to the MINISTAB system for operation of the altitude hold function. The method of altitude hold utilized is differential pitch, in that the aircraft will trade airspeed for altitude via aircraft pitch to maintain altitude. The altitude hold function does not operate unless the ADC senses, through an airspeed switch and differential pressure transducer, that the helicopter has an airspeed of greater than 40 Knots Indicated Airspeed (KIAS). When altitude hold is engaged, an altitude transducer provides barometric data to a digital altitude integrated circuit, which generates a signal proportional to the error between actual altitude and altitude at the moment of engagement. The system will then try to drive that error to zero by the ADC sending commands to the pitch and roll AFCS computers. The AFCS computers then make rotor pitch inputs to gain or loss altitude, by commanding the longitudinal and lateral AFCS actuators. The barometric reference used by the ADC can be reset and referenced by either resetting the ALT button on the MINISTAB controller panel, or by pressing and releasing the FT button on the cyclic once the altitude hold system is engaged.

Principle of Operation

The MINISTAB is designed to be a transparent flight control system, where the AFCS system does not interfere with operator inputs to the flight controls at any time. Additionally, the AFCS system flight control inputs are not apparent to the operator throught the flight controls. More importantly, the operator is able to “over-ride” AFCS control inputs at all times to fly the aircraft via standard flight control inputs.

RATE DAMPING

The rate damping function of the system provides apparent gust alleviation, in that the AFCS system attempts to eliminated or greatly reduce the magnitude of short-term disturbances to the aircraft in each axis of augmentation. This is accomplished by the system detecting an angular acceleration in a particular axis, and then entering an AFCS actuator input to counter the measured rate, attempting to keep it the axis angular rate at 0 deg/sec. The response of the system is limited to the speed and control authority of the AFCS actuators. Disturbances to the system can come from external sources such as a wind gust, or from internal sources such as an abrupt or fast flight control input via the cyclic or yaw pedals. This function of the MINISTAB is always present as long as the AFCS is on.

ATTITUDE RETENTION

Attitude retention function of the MINISTAB system is designed to hold a set attitude (pitch and roll) or relative heading (yaw) for <u>several minutes</u> at a time.   With the attitude hold function of the AFCS engaged, the individual AFCS computers perform an integration of the remaining angular rate of the assigned axis over time after gust alleviation counters a disturbances. It then uses that integration value to apply an additional correction signal to the AFCS actuators to bring the aircraft back to its original set attitude. When the attitude hold function for a particular axis is disengaged, the system will go into mode know as Integration Cut Off (ICO), where the integration correction to the AFCS actuators is removed and the attitude hold function goes into a “stand-by” mode.   While the system is in ICO, the aircraft will retain the rate dampening functions of the MINISTAB system.

The MINISTAB Control Laws function as:

1) The AFCS will go into ICO with the STAB button engaged when **<u>one</u>** of the following occurs:
   a) Pitch or roll:
      i) The CMD is activated for that axis by any force/pressure applied against force trim. As a result the operator can individually ICO the pitch or roll axis by making a cyclic control input against force trim in that axis only.
      ii) The cyclic force trim button is depressed which releases both pitch and roll axes.
   b) Yaw: the yaw pedals micro switch is activated for yaw.
   c) The angular rate about a particular axis is greater than 1.5 deg/sec.
2) The Integration Correction (or attitude hold) is applied/reapplied when **<u>all</u>** of the following conditions are met:
   a) Pitch and roll: no control input is applied against force trim for that axis <u>AND</u> the cyclic Force Trim button is released.
   b) Yaw: The yaw micro switch is not activated.
   c) The angular rate about that axis falls below 1.5 deg/sec for at least 900 milliseconds.
3) Turn Coordination: When the roll computer senses an ICO in the roll axis, it sends a signal to the yaw computer to ICO the yaw axis as well. This prevents the yaw axis relative heading hold from resisting the operator’s turn, which would result in an unbalanced turn.

<u>Method of Operation</u>

GENERAL

In principle the MINISTAB system assists the pilot to maintain a desired aircraft attitude, once the aircraft is in a steady state. The system is a low gain system with limited control authority, meaning that the system is unable to compensate for large attitude or heading errors. It is also an analog system, in which errors can built up over time forcing the operator to reset the system. In order to employ the system effectively, these factors combined with system control laws dictate a control strategy. In general the system is designed to allow the pilot to incrementally adjust around a steady "trimmed" aircraft attitude. Because of this, the system responds most effectively when MINISTAB inputs are made in one axis at a time. For new operators, the generally recommended initial control technique is:

1) With the cyclic force trim button depressed and the yaw micro-switch activated (all axes in ICO with all force trim eliminated) adjust all controls until the aircraft is steady on the desired flight profile parameters.
2) Release the cyclic force trim button and reduce pressure on yaw pedals (deactivate the yaw micro-switch).
3) Take a moment to observe if the desired trimmed aircraft state was successfully achieved.
4) If required. <u>Without</u> depressing the cyclic force trim button, make small corrections of up to 5 deg in pitch (for airspeed) and roll.
5) If adjustments are required for balanced flight (i.e. the ball is out), apply even pressure to both pedals to activate the yaw micro-switch, adjust the pedal position, and release pedal pressure. This step is important in that pitch/roll augmentation control is separate from yaw augmentation, and will also be required with each collective position change.
6) If the system will not retain the desired attitude and resulting flight parameters, or small inputs are not registered by the system in that the aircraft returns to an undesired attitude, return to Step 1 and repeat.

TURNING FLIGHT

It is important to recognize that the yaw AFCS function operates independently from the pitch and roll AFCS functions, with one exception for "turn coordination." The MINISTAB will engage this feature when the aircraft is greater than 40 KIAS. When a roll ICO is detected by the MINISTAB, the system will also ICO the yaw axis. The system "assumes" that with a roll ICO the operator is attempting to turn, so the system will ICO the yaw axis so that AFCS will not work against the operator in maintaining a balance turn. This system ability to retain a trimmed attitude required for a turn can be used by the operator to greatly reduce workload. The suggested method for the new operator to execute a turn is:

1) For angles of bank of 15 deg or less, <u>without</u> depressing the cyclic trim button, roll the aircraft at a moderate rate to the desired roll attitude against force trim. Once the desired roll attitude is achieved, slowly remove the control input, releasing the pressure against the force trim.
2) For angles of bank from 15 deg to 30 deg, depress the cyclic trim button and roll the aircraft at a moderate rate to the desired roll attitude. Steady the aircraft attitude at the desired angle of bank and release the cyclic trim button.

3) For angles of bank greater than 30 deg, the control forces and aircraft dynamics are generally too great to maintain a desired attitude. It is recommended the operator continually apply control inputs with or without depressing the cyclic trim button.
4) For Case A and Case B, once the aircraft is steady at the desired angle of bank, the basic control strategy present in the previous paragraph is usually effective.

COMMON MINISTAB ERRORS

New operators typically make a few common errors, based primarily on unfamiliarity with the aircraft and the operation of the MINISTAB system.

1) "Mixing" with cyclic – This error occurs when the operator is constantly making small inputs in pitch and roll axes, trying to get to the desired aircraft attitude. As a result the MINISTAB is in a constant state of applying and removing the ICO condition to the related axes, due to the initial control input and the required system time delay. This creates a condition in which the system never attempts to maintain an initial aircraft attitude which can then be effectively adjusted. Additionally, the operator's inputs will also be resisted by the rate dampening portion of the system.
2) Combined inputs – This error occurs when on operator attempts to make a pitch and roll adjustment simultaneously. This type of input is problematic due aircrafts reaction to the input which generally couples to all three control axes, which can exceed the capability of the MINISTAB system and confuse the operator. This type of control input during trimmed flight violates the designed and intended use of the system.
3) Machine gun the cyclic button – When the operator is attempting to set a desired attitude, at times they will in a rapid fashion, repeatedly depress the cyclic trim button. These constant depressions of the cyclic trim button effectively place the pitch and roll axes in a constant ICO state.
4) "Trading airspeed for altitude" – It is recommended that new operators of the MINISTAB should not attempt to correct altitude errors with aircraft pitch changes. Due to the operational behavior and characteristic of the MINISTAB system, corrections of this type are difficult without a reasonable amount of flight experience with the system. The new operators should attempt to moderate corrections for altitude with collective inputs, and moderate corrections for airspeed with pitch corrections only.
5) "Fighting the pedals" – It is important to remember that the relative heading hold and rate damping of the pedals/yaw axis is always on, and that the only way to release and ICO the yaw axis is to activate the pedal micro switch. If the operator attempts to make a pedal adjustment without activating the pedal micro switch, the operator will essentially be "fighting" against both functions of the MINISTAB: the aircraft will counter the heading correction by trying to hold its set heading, and counter the desired yaw rate that the operator is trying to make. This problem is especially problematic during hovering pedal turns. The recommended technique for either making pedal adjustment, or making a prolonged pedal input is to apply even pressure on both pedals to release trim and ICO the yaw axis, and

continue applying that pressure until either the adjustment is made or the maneuver is complete.

6) Forgetting to re-set yaw pedals when trimming the aircraft – While adjusting the flight attitude of the aircraft, new operators usually neglect to adjust the yaw axis, which attempting to hold the relative heading which the operator initially set. For instance, while trying to fine tune a heading with small roll inputs, the yaw AFCS may be fighting these adjustment. Many times, yaw trim adjustments may be needed for fine adjustment to maintain a heading by utilizing the pedal micro-switch to reset the yaw axis via a momentary ICO. Often times when the operator is having difficult at fine heading maintenance, the ball is trimmed into out of balanced flight by the MINISTAB.

ALTITUDE HOLD

The attitude hold function of the MINISTAB is designed to maintain a set barometric altitude by differential pitch. At approximately 40 KIAS the Airspeed Switch closes and allows the activation of altitude hold, which is accomplished by pressing the ALT pushbutton on the FCS Controller. Use of the ALT switch requires the STAB switch also be active and functioning. The system will then attempt to hold the altitude at which the ALT pushbutton was activated by pitching the aircraft up or down. Changes in pitch attitudes to climb or descend are achieved by commands sent from the air data computer to the cyclic AFCS actuators. Additionally, the set altitude may then be reset by pressing the cyclic force trim button. The system will attempt to hold the set altitude until an error of approximately +/- 150 ft is measured, at which point the system will disengage. Additionally, while the system is engaged the operator is able to make control inputs in all axes, however the system will not hold a set pitch attitude, but rather a set aircraft altitude. It should be stressed that reliability of the system is dependant to the trimmed condition of the aircraft at the time of altitude hold engagement.

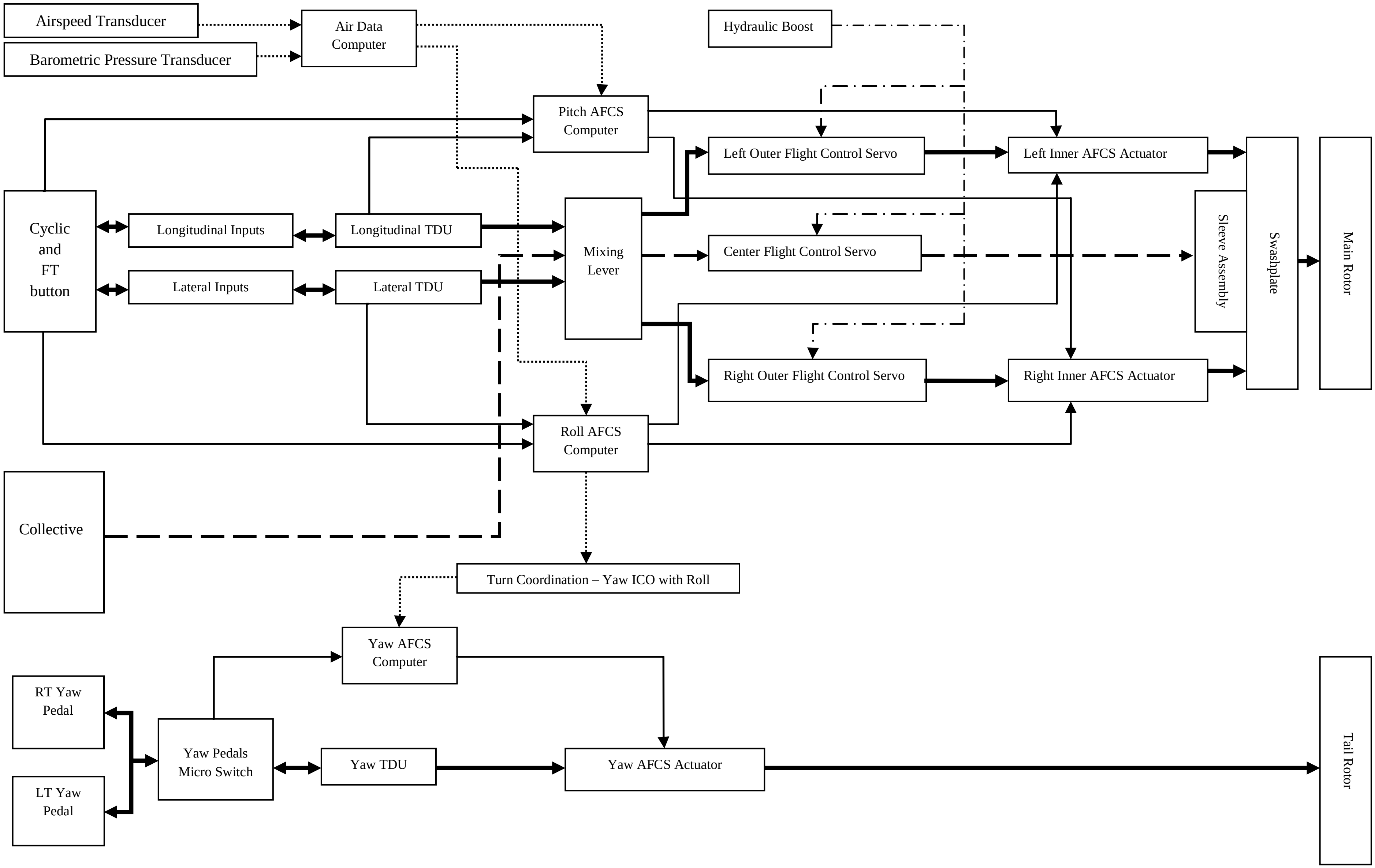

Figure 1: MINISTAB Functional Diagram

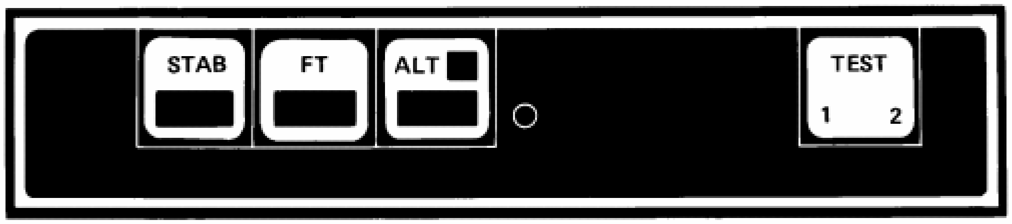

Figure 2: MINISTAB Controller

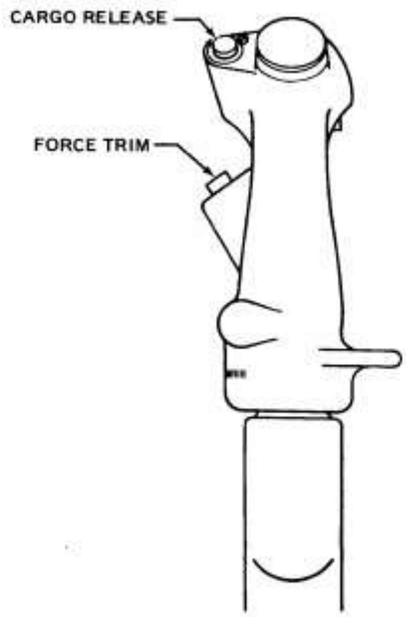

Figure 3: Cyclic “FT” Force Trim release button

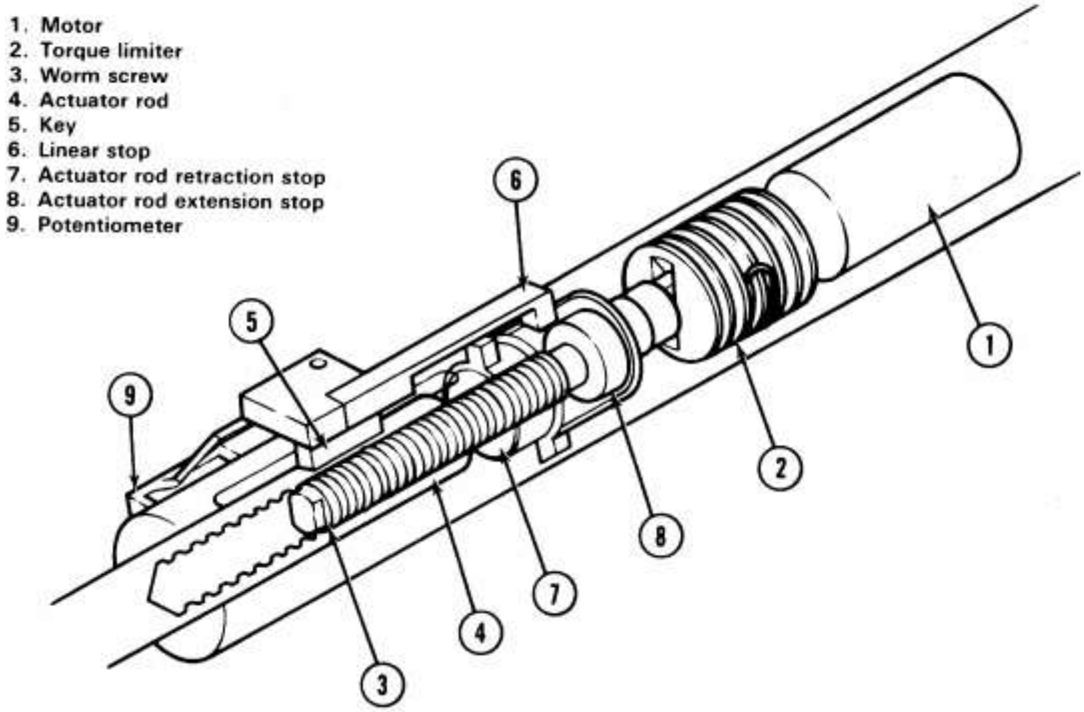

Figure 3: Actuator Assemblies

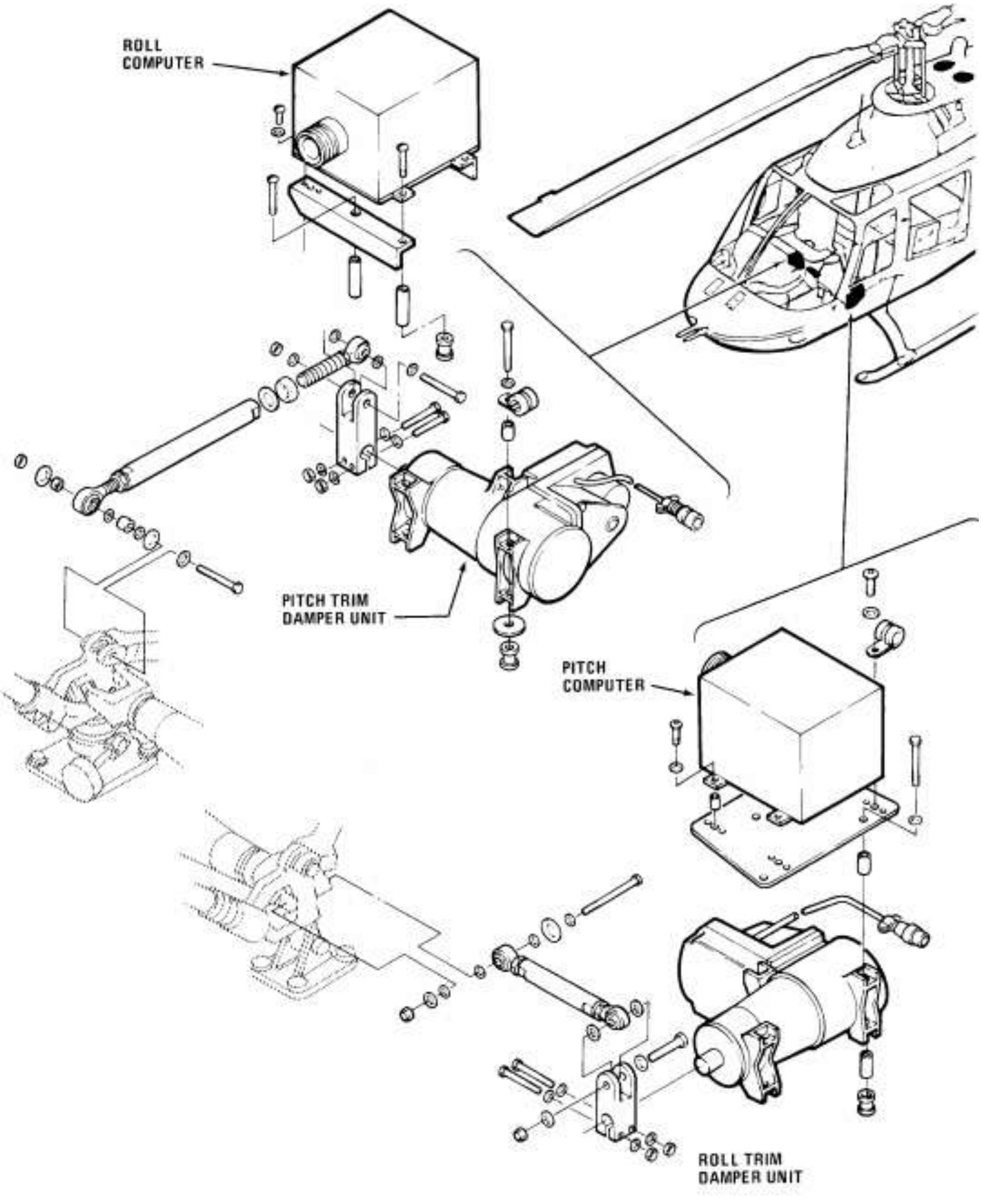

Figure 4: MINISTAB Pitch and Roll TDU and Computer