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SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.
485 LEXINGTON AVENUE
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AERONAUTICAL RECOMMENDED PRACTICE

ARP 419

AUTOMATIC PILOT INSTALLATIONS

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Revised

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1. PURPOSE: This Aeronautical Recommended Practice is intended to outline Automatic Pilot installation design, performance, and test recommendations for use as a guide by the aircraft industry.

2. SCOPE: These recommendations cover the mechanical and electrical installation and installation test procedures for automatic pilots of the type normally used in transport type aircraft. The material in this ARP does not supercede any airworthiness requirement in the Civil Air Regulations.

3. GENERAL REQUIREMENTS:

3.1 Equipment: The automatic pilots referred to herein should conform to Aeronautical Standard AS-402A.

3.2 Materials: Materials should be of a quality which experience and/or tests have demonstrated to be suitable and dependable for aircraft use.

3.3 Workmanship: Workmanship should be consistent with high grade aircraft manufacturing practice.

3.4 Environmental Conditions: The design of the installation should be such that satisfactory performance may be obtained under the environmental conditions to which the aircraft may be subjected.

3.5 Installation Survey and Component Selection: In order to provide information relative to the aircraft aerodynamic and structural characteristics, an "Installation Survey" form is included as Appendix "A" of this ARP. The aircraft manufacturer should, to the best of his ability with respect to the aircraft design status, supply the automatic pilot manufacturer with the information called for on this form. Along with this survey the aircraft manufacturer should also specify any automatic pilot component characteristics which may be deemed necessary to provide a closer integration of the automatic pilot with the basic aircraft control system.

On the basis of this information, the automatic pilot manufacturer should then design, select, and combine the necessary components into a comprehensive system which can be expected to perform the desired and necessary fuctions in accordance with AS-402A, and not induce aerodynamic or structural loads in excess of the design limits specified by the aircraft manufacturer. Final values of maximum servo forces and signal calibration should be checked and determined on the basis of flight tests of the initial installation.

4. DETAIL REQUIREMENTS:

4.1 Mechanical:

4.1.1 Control Surface Actuators (Servos):

4.1.1.1 Location and Mounting: The location and mounting of the servo should be carefully considered from the standpoint of control system friction, preloads, lost motion, and other such characteristics which would tend to cause automatic control difficulties.

Locations should also be chosen to permit the shortest practicable connecting cables or links. Adequate clearance should be provided between the moving parts of the servo and adjacent structure to prevent possible jamming by foreign objects.

The servo mounting bracket should be designed with sufficient rigidity to prevent any detrimental deflection under conditions of maximum servo force. The use of vibration isolators should not be considered.

4.1.1.2 Connections and Rigging: The servo should be connected to the main control system so that it will produce uniform force and displacement in both directions of operation. In servo installations utilizing cable control, a parallel cable installation is preferred over the series installation. Cable installations designed for direct attachment to a bell crank or surface horn should be made through a suitable sector designed as an integral part of the horn or bell crank. The design of the sector should be such that full travel of the control system will provide a negligible change in servo cable tension. Where the cable runs over the servo drum, and has an angular motion with respect to the plane of the drum, the maximum misalignment resulting from this motion should not exceed 1 degree for the neutral position of the controls nor 3 degrees for any position between half and full movement of the controls. Each servo cable keeper should be positioned as close as possible to the point of tangency between the servo drum and cable.

Care should be taken in the design of the cable routing to prevent the possibility of foreign objects from lodging between the cable and the drum. If necessary, a suitable guard should be installed.

All control routing to the servos should be designed such that the minimum amount of friction will be added to the aircraft control system. Cabling details should be consistent with the general design practices which have been carried out in the manual control system. (See references 4 and 5).

4.1.2 Engaging Systems:

4.1.2.1 Cockpit Controls: If mechanical engaging and/or disengaging is utilized, the cockpit control handle should be so located that it is readily accessible to both pilot and copilot and as close to the flight controller and as distinctive in method and direction of operation as practicable. Forward or upward motion of the cockpit control should engage the automatic pilot system while motion in the opposite directions should disengage. (If engaging and disengaging is accomplished electrically the motion of the control switch handle shall be similar.) If necessary, the control handle should be provided with suitable guard to prevent inadvertent operation of the automatic pilot. The handle should be so located to enable a force not to exceed 35 lbs. to be readily applied.

4.1.2.2 Cables or Rod Controls: All Control Cables and/or Control Rods used in a mechanical engaging system should be so routed that they provide the minimum of friction. A maximum load of 35 lbs. should be presented to the pilot at the cockpit control. This load should be the total of the friction plus disconnect load.

4.1.3 Follow-up Controls:

4.1.3.1 Location: To permit the minimum of lost motion or deadspot to be maintained in the connecting linkage the follow-up control unit, if not a part of the servo, should be located in the control cable system as near as possible to the servo drum or other portion of the control system, the movement of which is being measured.

4.1.3.2 Connection and Mounting: Follow-up control units may be mounted in any position, but provisions should be made to enable either the shaft or the housing of the unit to be rotated for orientations of the electrical signal element. Connections should be made to the control system by means of push-pull rods and ball joints, control cables, or other suitable means which will transmit motion of the control system to the follow-up control unit shaft without lost motion. The connecting linkage should be such that the movement of the control system through its full travel will rotate the follow-up control shaft safely within the limits of its mechanical range, and in a manner compatible with system requirements. e.g. - a linear or non-linear function.

4.1.4 Control Valves and Piping: Electro-hydraulic control valves should be located immediately adjacent to their respective hydraulic boost or power control valves on the pilot's side of the boost, where applicable. They should be mounted securely in such a manner so as to prevent misalignment and/or twisting of any actuated parts.

All hydraulic piping and valves should be kept out of the cockpit area and away from oxygen lines or equipment, wherever possible.

4.1.5 Reference Components and Amplifiers: Accelerometers, pendulums, rate and displacement gyros, or other such reference devices should be installed such that their orientation, and location with respect to the aircraft's axes and center of gravity, will be in accordance with the manufacturer's recommendations.

The altitude sensor should be located as near as practicable to the source of static pressure, and suitably shock-mounted and oriented in a manner to preclude any undesirable effects of vibration and acceleration.

Amplifiers and coupling units should be mounted so as to allow accessibility to all tap switch or potentiometer adjustments.

4.1.6 Controller and Function Selector Panel: These units should be situated side by side and located in a position that is visible and readily accessible for operation by both pilot and copilot in their normal positions. The axes of the controller knobs or wheels should be oriented with those of the aircraft.

The function selector panel should be adequately lighted for night use. Where toggle switches are used, the function should be switched "ON" by a forward, or upward motion of the switch handle.

4.1.7 General:

4.1.7.1 Mounting Brackets: All mounting brackets should be designed to provide adequate strength, freedom from vibration and flexing that would interfere with the satisfactory operation of the automatic pilot under any flight conditions encountered in service.

4.1.7.2 Ventilation: All components should be installed in accordance with the temperature requirements of the equipment. If it is impossible to so locate the equipment in the aircraft which has temperature similar to that required, then provisions to direct cooling air to this equipment must be made.

4.1.7.3 Safety: All attaching fittings and fasteners such as bolts, nuts, clevis pins, etc., if not of the self locking type should be locked with safety wire or cotter pins.

4.1.7.4 Bonding: The chassis or mounting frames of all components should be electrically bonded to the aircraft structure. All mating surfaces which conduct a ground return should be clear of paint, anodized coating or other non-conducting materials.

4.1.7.5 Shock Mounts: The installation of connectors and connecting cables should be designed to minimize the effect of their added weight on vibration-isolated equipment. This item assumes greater importance where light-weight components are shock-mounted and the added weight of the attached cable and connector constitutes a significant part of the shock-mount load.

4.2 Electrical:

4.2.1 Power Supplies: The design of the electrical installation and the selection of the power supply components should conform to the best aeronautical practice and shall have ample capacity for cold starts to be encountered in service. Intermittent loads, other than the automatic pilot should be carefully considered with regard to automatic pilot performance. Where variations in voltage and frequency critically affect automatic pilot performance indicating meters should be provided for these functions.

4.2.1.1 A.C. and D.C.: Voltages and frequencies supplied to the automatic pilot should be in accordance with its established design ratings.

4.2.2 Wiring: Connections should be made in accordance with the wiring diagrams supplied by the automatic pilot manufacturer. Power leads and circuit protective devices should be installed in accordance with standard practices or as recommended by the automatic pilot manufacturer.

Electrical cabling and wiring should be adequate to meet such requirements as maximum allowable voltage drop, lead resistance, and current as recommended for the automatic pilot installation. References 1 and 2 may be used as a guide for aircraft wiring.

4.2.3 Shielding and Grounding: Strict conformance to the shielding recommendations supplied by the automatic pilot manufacturer should be followed in all installations to eliminate any possibility of spurious control signals. Where shielding is grounded at specified locations, the signal leads should be enclosed in sleeving to insulate the shielding from other circuits and ground contacts with the aircraft structure.

4.2.4 Switches, Signal Devices, and Interlocks: These items should be installed and electrically interconnected into the system, in accordance with the instructions of the automatic pilot manufacturer to insure that adequate protection of the aircraft and the automatic pilot is maintained.

4.2.5 Engaging System:

4.2.6 Cockpit Control: Both pilot and copilot should have an electrical push button for instant deactivation of all servos. Each switch should be located on the wheel side opposite the throttle hand. The electrical power or Autopilot "ON-OFF" switch should be located in a position easily accessible to both pilots.

4.3 Maintenance:

4.3.1 Accessibility: Ready access should be provided for service points such as lubrication, adjustment, dehydrators, and other items requiring attention while the automatic pilot is installed in the airplane. Units requiring frequent replacement should be located to provide for ease of removal. The installation of such units behind stress panels, and other units which require prior removal for access should be avoided wherever possible. Where units are located behind non-stressed panels, the use of quick-fasteners is recommended for attaching the panel.

4.3.2 Clearances: Adequate clearance should be provided for:

(1) Normal movement of the unit during flexing of shock mounts.
(2) Removal of electrical or mechanical connections.
(3) The use of tools required for removing and installing attachments.
(4) Removing the unit completely from the aircraft, through openings and around other items.

4.3.3 Replaceability: Location of mounting nuts, bolt holes, and other such fasteners that are required should be governed by the tolerances of the matching unit being installed. The alteration of a component to match the aircraft fittings should be avoided in the interests of interchangeability. Where shims are required to align the unit they should be attached to, and become a permanent part of the aircraft. Use of the following devices is recommended wherever possible to facilitate replaceability:

(1) Vibration-proof nuts.
(2) Nut plates attached to mounting brackets.
(3) Mounting subplates equipped with quick fasteners.
(4) Electrical disconnect plugs in lieu of terminal strips. (Except in low current carrying circuits such as those found in the compass transmitter leads in which case the number of disconnect plugs should be kept to a minimum.)

4.3.3.1 Hardware: The use of standard aircraft hardware ("AN" or "NAS") is recommended wherever possible.

4.3.4 Interchangeability: All components of a like type and function should be interchangeable with no further field modifications or internal adjustments at the time the unit is installed.

Where external adjustments are required to permit components to be used in different type aircraft or different portions of the system, it is recommended that instructions for making the adjustment be placed on the unit wherever possible. Where two units appear identical but produce different operating characteristics which, if misplaced, would tend to cause malfunctioning, means should be provided, such as dowel locating pins, or other such devices to physically prevent the components from being improperly installed. Where two or more components, having different functions but possessing identical connectors, are adjacent, means should be provided to physically prevent crossed connections. Example: Two different gyro units or servo units located side-by-side and having the same type of electrical connectors. Each connector cable should be clamped close enough to the proper unit to prevent it from being cross connected to the wrong unit. The use of placards, color coding, and other marking can be used but should not be relied upon for complete protection.

4.3.5 Field Tester Provisions: Consideration should be given for providing suitable test receptacles for the attachment of field test equipment without removal of the units under test.

5. TESTS: The manufacturer's recommendations regarding any special test equipment required, and specific tests to be performed, should be utilized in conjunction with the following:

5.1 Ground Tests:

5.1.1 Mechanical Installation:

5.1.1.1 Mounting: All component mounting bases and brackets should be inspected for security of attachment to the basic structure and the components themselves for security of attachment to their respective mounting bases. Servo mounting brackets should be inspected under maximum load conditions for any excessive flexing or deformation.

5.1.1.2 Rigging: All servo cable leads and linkages should be checked for proper tension tightness and inspected for clearance and friction through the full throw of the controls. Turnbuckles and fittings should be checked for safetying and tightness.

5.1.1.3 Static and Dynamic Pressure Source Leak Test: The static and dynamic pressure systems to which the air data sensors are connected should be tested for leaks by use of a sensitive manometer and suitable fittings. Test pressures should be determined for the particular installation depending on whether or not cabin pressurization exists on the aircraft.

CAUTION: EVERY PRECAUTION SHOULD BE TAKEN TO PREVENT DAMAGE TO THE SENSITIVE DIAPHRAGM MECHANISMS OF THE DATA SENSORS.

5.1.2 Electrical Installation:

5.1.2.1 Insulation Resistance: The insulation resistance between all possible pairs of unconnected leads and between each lead and ground should not be less than 5 megohms when measured with 500 volts D. C.

5.1.2.2 Continuity: After soldered connections are completed and before connecting the mating receptacles and plugs to units, the wiring should be checked with a low-voltage ohmmeter for continuity. The interconnection wiring diagram should be followed and checks should be made between all connected terminals on connection plugs or receptacles, relays, junction boxes, etc. A check should be made through all switches for closed circuits with switch closed and open circuit with switch open. A check should be made for shielding continuity to make certain that the proper ground connection has been made:

NOTE: NUMEROUS ELECTRICAL FAILURES MAY BE TRACED TO DAMAGED PLUG INSERTS RESULTING FROM THE IMPROPER USE OF OHMMETER PRODS IN CHECKING CONTINUITY. TO AVOID FORCING OR DISTORTING THE INSERTS, USE AN OHMMETER WITH A RECEPTACLE PIN SOLDERED ON EACH PROD. PINS IN GOOD CONDITION, FROM ANY DISCARDED RECEPTACLE WILL SERVE THE PURPOSE.

5.1.2.3 Visual Inspection: All soldered connections, junctions and receptacles should be inspected for soundness of mechanical and electrical connections, as well as acceptability of the junction or receptacle. Cables should be inspected for fraying, pinching, or damage to shielding or insulation.

5.1.2.4 Power Supply: Measurements should be made to determine if the D.C. Voltage, and the A.C. voltage and frequency (to which the automatic pilot is connected) are within the specified tolerances with the automatic pilot both "OFF" and "ON". The "ON" measurements should be made after the automatic pilot has been in operation for at least three minutes.

5.1.3 System Adjustments:

5.1.3.1 Compass Compensation: The compass system used for a directional reference should be swung against known magnetic headings in accordance with the manufacturer's recommendations. Every attempt should be made to remove the "lubber line" or index error of the compass transmitter before applying any required magnetic or mechanical compensation.

5.1.3.2 Servo Overpowering Forces: If the installation is so designed as to permit the servos to be manually overpowered by the human pilot, the servos should be adjusted so that the force at the pilots controls will not exceed the following values for the entire system (system friction plus servo stall force).

Rudder	150 lbs.	
Aileron	30 lbs.	(as measured at the rim of the wheel)
Elevator	50 lbs.	(as measured at the center of the wheel)

5.1.3.3 Limit Switches: All limit switches should be adjusted to their initial values followed by a number of repetitive operational checks to make certain they will maintain their settings within their specified tolerance.

5.1.3.4 Control Valves: The control valves are to be checked to see that they are properly mounted with all connections complete and adjusted to give the desired control surface travel and force.

5.1.3.5 Servo Engagement and Disengagement:

5.1.3.5.1 Mechanical: Cable rigging and/or linkages should be adjusted for correct tension, travel, and allowable load at the engaging handle.

5.1.3.5.2 Electrical: The automatic pilot should be engaged and disengaged electrically and the control surfaces checked to note any flicker motion or control displacement. If any abnormal control surface change occurs, the necessary adjustments to the clutch, follow-up units, synchronizing circuits, etc., should be made. Clutches should be checked to see that they disengage satisfactorily under both "no-load" and "full load" conditions. Upon disengagement, check to see that the controls are free and without excessive friction.

5.1.3.6 Signal Calibration: Pending final establishment of desired signal calibration levels by means of flight tests, the signal calibration levels should be set in accordance with the automatic pilot manufacturer's preliminary recommendations resulting from analytical studies of the system.

5.1.4 System Operation:

5.1.4.1 Interlock Check: All electrical and mechanical interlock combinations which have been incorporated in the design of the automatic pilot should be checked for correct functioning and sequence before placing the autopilot in operation.

5.1.4.2 Servo Direction and Synchronization:

5.1.4.2.1 Controller: With the power on, the automatic pilot engaged, rotation of the bank and pitch adjustment should result in corresponding motion of the elevators and ailerons. Rotation of the turn adjustment should result in corresponding aileron motion. Corresponding rudder and up-elevator motion should also be checked if the system is designed to provide these controls during a turn command.

NOTE: During ground tests, the counter-effect of control system balance weights or spring loads may exceed the maximum servo force provided for in-flight operation, thus causing the servo to be stalled, and preventing actuation of the controls. In such instances, the servo may be temporarily disengaged from the control system to enable the necessary command signal tests to be accomplished.

If command control is initiated through control wheel sensors, control direction should correspond to the wheel movement. Response should occur within the specified threshold values of the sensors.

5.1.4.2.2 Corrective Control Signal: With the power on, the automatic pilot engaged, and the command controller in neutral (straight and level flight), movement of the attitude gyro in bank or in pitch should result in displacement of control surfaces in a direction to correct the original reference movement. If elevator compensation (for turns) is provided in the vertical gyro, corresponding up-elevator will also result from gyro movements in bank. Movement of the compass signal source indicating a divergence in heading to the right should result in a left turn. Movement of the compass signal source to the left should result in a right turn.

NOTE: With rate gyros, corrective signals are generated by continuous motion of unit in the proper direction and sense. With inertial devices such as accelerometers, corrective signals are generated by changes in rate of motion. When motion ceases, the servo system should drive to the system null. The above test procedures should be modified for rate gyro and inertial type sensors where applicable.

5.1.4.3 Automatic Trim: Each automatic trim servo should be made to run at its installed maximum speed. Direction of rotation should be checked for agreement with command used to initiate rotation.

Limits - Where limits of travel for the automatic trim servo have been established, the trim servo should be run to each end of its travel as determined by the travel limiting device. The servo should stop consistently within ± 10% of the nominal value established for each travel limit.

5.1.4.4 Trim, Attitude and Direction Indication: Trim indication should be such as to indicate the direction of applied control force. For example, a down elevator force thus resulting in a nose down motion of the aircraft should be indicated by a down pointer deflection. Where attitude and direction are indicated by associated components such existing indications should be checked for accuracy against known attitudes and directions.

5.1.4.5 Altitude Control: With the power on, the automatic pilot engaged, the controller in neutral and the altitude control switch "ON" an increase in pressure at the altitude control should result in up elevator motion. A decrease in pressure at the altitude control should result in a down elevator motion.

5.1.4.6 Radio - Automatic Pilot Coupler: Input signals to the coupler, either from the radio receivers or their equivalent from a signal generator should be checked to see that they produce the proper corrective control. On new installations, it is recommended that the above check be performed with the input signal originating from the radio receivers, using a radio frequency signal generator to activate the receivers.

5.2 Flight Test:

5.2.1 Interlocks: All checks performed under 5.1.4.1 should be repeated in flight.

5.2.2 Servo Engage and Disengage: The servos should be engaged and disengaged mechanically and/or electrically for all flight attitudes at which engagement and disengagement is likely to take place. No abrupt movement or appreciable change in direction or attitude of the airplane should occur. (Note that there are autopilot systems which are designed to return the airplane to straight and level flight when engaged during any other attitude. If so, this should be done without appreciable overshoot, oscillation, or abrupt action.)

These tests, and those specified in the following paragraphs should be conducted in smooth air, and calibration adjustments made where required.

5.2.3 Servo Overpowering and Recovery: If the servos and their installations have been adjusted to permit overpowering by the human pilot the following checks should be made; The airplane should be trimmed for straight and level flight and the automatic pilot engaged. Each axis should then be overpowered to deviate the aircraft from straight and level flight. Overpower control should then be released and the response of the aircraft checked. The aircraft should return to straight and level flight in all cases without appreciable overshoot, undershoot, undamped oscillation or abrupt action. The maximum overpowering forces should not exceed those recommended in paragraph 5.1.3.2.

(On those axes possessing automatic trim servos, precautions should be exercised during overpowering to prevent excessive trim tab displacement from occurring. During overpower in pitch, the automatic pitch trim and altitude control should be disengaged).

5.2.4 Stability-Normal Flight:

5.2.4.1 Roll: During normal level flight in smooth air no noticeable motion in roll should exist. Induced transients on the roll axis should damp out smoothly. Roll stability should be within the limits specified in AS402A.

5.2.4.2 Pitch: During normal level flight in smooth air, no noticeable oscillatory or repetitive pitch change should occur. Induced transients should damp out smoothly. Operation specified in this paragraph is without altitude control. Pitch stability should be within the limits specified in AS 402A.

5.2.4.3 Yaw: There should be no noticeable indication of oscillation in smooth air and an induced transient should damp out smoothly.

5.2.4.4 Heading: During normal level flight in smooth air, the airplane heading should remain within the limits specified in AS402A.

5.2.5 Command Control:

5.2.5.1 Turn: The maneuvering limit in turns should be as specified in AS402A.

5.2.5.2 Pitch: The maneuvering limits in pitch should conform with the requirements in AS402A.

5.2.5.3 Bank: The operating limits in bank should conform to AS402A.

5.2.6 Altitude Control: Performance should be tested at both cruising and approach speed, in both straight flight and turns.

The altitude control pitch attitude limit should conform to AS402A.

5.2.7 Magnetic Heading Control: The magnetic heading reference should be checked for accuracy and stability with landing gear both up and down, and under all conditions of electrical loads, and normal flight maneuvers.

5.2.8 Throttle Control: If throttle control is used, its response and recovery from transients should be checked both up and down while on the glide slope. Transients may be introduced either electrically or by manually overpowering the controls.

5.2.9 Airspeed Control: If airspeed control is used, it should be checked for airspeed stability within the design limits of the equipment. Transient response should also be tested.

5.2.10 Electrical Power Variation: Tests should be made to determine the D.C. voltage and the A.C. voltage and frequency received by the automatic pilot while the electrical loads are varied in a manner likely to be encountered in service. Consideration shall be given to "engine-out" conditions. During the above test, there should be no adverse control reaction by the automatic pilot due to variations of the power supply, nor by the switching of other electrical loads.

5.2.11 Servo Force Limits: To prevent the automatic pilot from exceeding aircraft maneuvering load limits in the event of an actual malfunction during service, means should be provided for limiting the force output of each primary control surface servo to a maximum value. These values should be determined through flight tests of the prototype installation. A simulated signal source capable of producing maximum servo forces may be used during these tests. Aircraft maneuvering loads limits should be determined on the basis of the airframe manufacturer's recommendations, and applicable Civil Air Regulations.

5.2.12 Automatic Trim:

5.2.12.1 Direction and Speed: On each axis in which an automatic trim servo is installed the surface control should be overpowered or a command signal introduced, and direction of the trim servo noted to be such as to correct the condition. If overpowered, release of the surface control should return both the main and trim servos to their normal positions. Any oscillations should damp out smoothly. The maximum trim servo speed should not exceed a value which in 5 seconds could result in an out-of-trim condition which will, under the most adverse c.g. position and speed of the airplane, produce accelerations exceeding established limits or result in structural damage. Minimum servo speed should not permit an out-of-trim condition which would be dangerous if the autopilot were to be disconnected.

5.2.12.2 Limits: The established travel limits for the automatic trim system should not be great enough to permit the trim servo after 5 seconds of operation at maximum speed to put the aircraft in a dangerous attitude, to result in accelerations above those allowed for the aircraft, or to cause structural damage to the aircraft within the licensed operating conditions of the aircraft-autopilot combination. Closer limits may be used but should provide sufficient range to trim the surface for all conditions of weight, c.g., and speed for which the autopilot is licensed on the aircraft.

5.2.13 Radio-Automatic Pilot Coupler:

5.2.13.1 Direction and Trim: Approaches to the localizer beam should be made at the most critical aircraft gross weight, airspeed, and loading conditions which could be encountered in normal service. Approaches should be made from either side of the beam at various intercept angles up to the maximum angle for which the equipment is designed. Altitude and distance from the runway at time of beam entry should be governed by standard instrument approach procedures.

The direction of turn and the bank angle should be checked for correct direction and maximum allowable values as determined by the design or initial adjustment of the coupler. The maximum bank angle should never exceed that recommended by the aircraft manufacturer for the load, airspeed, and c.g. factor on instrument approaches, or those bank limits specified by AS402A.

Bracketing of the beam should be accomplished by firm, positive control action, requiring the minimum number of overshoots to complete the action from the maximum angle of intercept. Two overshoots or less could be considered acceptable. Cockpit procedures with respect to the manipulation and timing of the autopilot controls should be governed by the design features of the automatic pilot. After initially stabilizing on the beam, the aircraft should show no tendency to oscillate or wander from the beam center.

5.2.13.2 Pitch: Interception of the glide slope should be accomplished with the minimum number of overshoots. Not more than two could be considered satisfactory.

After initially stabilizing on the beam the aircraft should have no tendency to oscillate or wander from the beam center during the remainder of the approach down to an altitude of at least 100 feet above the ground. The aircraft should be in a trimmed condition following disengagement of the autopilot.

5.2.13.3 Associated I.L.S. Equipment: During automatic approach tests, the I.L.S. facilities should be operating in accordance with existing CAA standards. Considerations should be given to possible local beam disturbances and inherent beam bends which may be encountered. Airborne Glide Slope and Localizer receivers used to provide signals to the automatic approach coupler should be calibrated and adjusted in accordance with current industry standards.

Further discussion of I.L.S. characteristics with recommended adjustment criteria will be found in Reference 8.

5.3 Post Flight:

5.3.1 Mechanical:

5.3.1.1 Mounting, Security and Condition: All components should be inspected for security of mounting and for any adverse effects of vibration, exposure, or overheating.

5.3.1.2 Rigging: Upon completion of the flight and landing, the following should be checked:

(1) Visual inspection for fraying, stretching or misalignment of the servo and aircraft control system cables.
(2) Manual check for loading, feel, friction, and general tightness of the control system cables.
(3) Manual check of alignment in pulleys and servo drums and looseness in servo and pulley mountings.

After tightening all attaching bolts, the automatic pilot system should then be engaged and controlled by the controller to check the overall operation of the system.

5.3.2 Electrical:

5.3.2.1 Connections and Wiring: All terminals and disconnect plugs should be inspected for tightness.

Junction boxes should be checked for the presence of any loose, irrelevent material.

5.3.2.2 Security and Condition: All junction box wiring, exposed wiring harnesses, and disconnect plugs should be inspected for security of attachment and for any adverse effects of vibration or exposure.

5.3.3 Settings and adjustments: Final calibration settings and adjustments arrived at during ground and flight tests should be locked and/or sealed, as required, and the values noted for use in subsequently replaced components in the subject aircraft.

REFERENCES

1.	"Design Manual on Aircraft Electrical Installations	- Available from: Aircraft Industries Assn. 610 Shoreham Building Washington 5, D. C.
2.	Specification MIL-W-5088B (ASG) "Installation of Aircraft Wiring"	Commanding Officer U. S. Naval Air Station Johnsville, Pennsylvania
3.	Specification MIL-E-7894A (ASG) "Characteristics of Aircraft Electric Power"	Commanding Officer U. S. Naval Air Station Johnsville, Pennsylvania Attention: Technical Records Division
4.	Civil Aeronautics Manual 4 "Aircraft Airworthiness"	The Superintendent of Documents U. S. Government Printing Office Washington 25, D. C.
5.	Specification ANC-5 "Strength of Metal Aircraft Elements"	The Superintendent of Documents U. S. Government Printing Office Washington 25, D. C.
6.	SAE Aeronautical Standard AS402A "Automatic Pilots"	Society of Automotive Engineers, Inc. 485 Lexington Avenue New York 17, N.Y.
7.	SAE Aeronautical Recommended Practice ARP 268A "Location and Actuation of Cockpit Controls for Commercial Transport type Aircraft."	Society of Automotive Engineers, Inc. 485 Lexington Avenue New York 17, N. Y.
8.	RTCA Paper 151-56/DO-74 "Automatic Flight"	Radio Technical Commission for Aeronautics. Room 2036, Building T-5 16th & Constitution Ave. NW Washington 25, D. C.

GLOSSARY OF TERMS

Airspeed Control — A function, or mode of operation, which provides constant airspeed by regulating the throttles in response to signals from an airspeed sensor.

Airspeed Sensor — A device which provides output signals proportional to airspeed pitot-static pressures.

Altitude Control — A function, or mode of operation which provides constant altitude by controlling the pitch attitude of the aircraft in response to signals from an altitude sensor.

Altitude Sensor — A barometric device which provides output signals proportional to the deviation from a reference pressure-altitude.

Attitude Gyro — A gyroscope which provides an output signal which is a measure of the aircraft's attitude with respect to a gravitational reference. (Also called vertical gyro)

Control Valve — A valve used to control the fluid flow of a hydraulic type servo. It operates in response to signals from a controller, selector, or sensor. (Also called a Boost Control Valve, or Power Boost Control Valve).

Controller — A device which permits the human pilot to initiate Turn, Pitch, and Bank Signals in the Automatic Pilot.

Follow-Up Control Unit — A device which provides an output signal proportional to the displacement, or rate of movement, of that which is being driven by the servo. (Also called a Feedback or Repeatback Control unit.)

Follow-Up Signal — A signal produced by a Follow-Up Control unit. (Also called a Feedback or Repeatback Control Unit.)

Function Selector — A device which permits the human pilot to select automatic pilot functions or modes of operation.

Glide Path — The path used by an aircraft in approach procedures as defined by an instrument landing facility.

Glide Slope — An included path in space which is defined by radio signals emanating from an instrument landing facility.

GLOSSARY OF TERMS (Continued)

Localizer — A radio facility which provides signals for use in lateral guidance of aircraft with respect to a runway centerline.

Overshoot — Movement of the aircraft whereby it coasts past the commanded reference altitude, attitude, or flight path before settling out.

Rate Gyro — A gyroscope which provides an output signal proportional to the turning rate about a given axis.

Servo — The actuating device which positions the aircraft control surfaces in response to a commanded signal from a controller, selector or sensor. (Also called a servomotor or servo actuator.)

Servo Engage Disengage — The process of connecting or disconnecting the servo motor and gear train from the cable drum or sector through a mechanical or electrical clutch in the servo.

Servo Overpower — The act of overpowering the servo by applying an appropriate pilot force at the control column or rudder pedals.

Signal — A measure or quantity of the medium used to communicate a condition, effect, or other desired intelligence from one point in the system to another. In an electrical system this may be a voltage; in a hydraulic system, a pressure. A signal may be generated by a sensor, controller or selector or other such reference device.

Throttle Control — A function or mode of operation which provides power or throttle control in response to pitch attitude, glide slope, or airspeed signals.

Transient — A temporary deviation of the aircraft from its normal attitude produced by momentarily overpowering the automatic controls or by momentarily injecting a signal to cause a deviation.

Trim Indicator — An instrument used to indicate the relative amount of servo effort being used to maintain the aircraft trim.

Undershoot — Movement of the aircraft whereby it stops short of the commanded reference altitude, attitude or flight path, before settling out.

ARP 419, AUTOMATIC PILOT INSTALLATIONS

APPENDIX A

AUTOMATIC PILOT INSTALLATIONS SURVEY

Issued 11/15/57

ARP 419
Appendix A

AUTOMATIC PILOT INSTALLATION SURVEY

Date Prepared ____________

1. Performance and Service

1.1 Aircraft Manufacturer ____________________ Designation ____________

1.2 Kind of Service ____

1.3 Engine Type ____________________________ Number of Engines ____________

1.4 Weight and Balance

1.4.1 Design Gross Weight __________ lbs. at C.G. ________________ % MAC

1.4.2 Maximum Take-Off Gr.Wt. __________ lbs. at C.G. ________________ % MAC

1.4.3 Minimum Landing Gr.Wt. __________ lbs. at C.G. ________________ % MAC

1.4.4 Curve of C.G. vs. Gr.Wt. for normal fuel sequencing.

1.5 Airspeed

1.5.1 If available, an altitude (feet) vs. airspeed (knots true) envelope should be provided. This will form the basis for selection of representative flight configurations as follows:

1.5.1.1 Maximum Indicated Airspeed at the altitude of its intersection with maximum power speed.

1.5.1.2 High Altitude, Maximum Speed at an altitude of 75-85% of the maximum altitude. This may correspond to the bombing configuration for bomber-type aircraft, or the fuel transfer condition for an in-flight refueler, for example.

1.5.1.3 Normal Cruise, usually well within the altitude-airspeed envelope.

1.5.1.4 Approach at Sea Level, with gear down and landing flaps extended.

1.5.2 Should the altitude-airspeed envelope not be available, the altitude and airspeed for the four configurations of 1.5.1 may be provided as follows:

1.5.2.1 Maximum _______ Knots IAS at ____________ feet.

1.5.2.2 Maximum _______ Knots TAS at ____________ feet.

1.5.2.3 Cruise _______ Knots IAS at ____________ feet.

1.5.2.4 Approach _______ Knots TAS at Sea Level.

1.5.3 Landing _______ Knots TAS at Sea Level.

1.6 Service Ceiling _________ feet.

2. Drawings

2.1 Outline Drawing of Aircraft Indicating:

2.1.1 Overall Dimensions.

2.1.2 Control Surface Dimensions.

2.1.3 Extreme Positions of Center of Gravity.

2.1.4 Proposed Locations of Automatic Pilot Components.

2.2 Mechanical schematics of rudder, aileron, elevator and throttle control systems, including trim systems and indicating hand and foot movements, servo travel, surface travel, servo attachment points and all linkage dimensions.

3. Control System Data

3.1 Plots of cable force in pounds and displacement in inches at the servo attachments points vs. surface motion in degrees from trim neutral in specified flight configurations for rudder, aileron and elevator, per attached Forms No. 1A and 1B. If boost control is optional in flight, this information is required for boost operative and inoperative.

3.2 Expected automatic pilot servo cable travel, hardover to hardover.

3.2.1 Rudder _____________________ inches.

3.2.2 Aileron _____________________ inches.

3.2.3 Elevator _____________________ inches.

3.3 Elevator servo cable force in pounds at servo attachment point per "g" of normal acceleration for the cruise and approach configurations for extreme forward and aft center of gravity positions.

3.3.1 Cruise at ____________ Knots IAS.

3.3.1.1 ___________ lb/g at __________________ % M.A.C.

3.3.1.2 ___________ lb/g at __________________ % M.A.C.

3.3.2 Approach at __________ Knots IAS.

3.3.2.1 _____________ lb/g at _________________ % M.A.C.

3.3.2.2 _____________ lb/g at _________________ % M.A.C.

3.4 Limit and Ultimate Load Factors in total normal "g's", positive and negative. (Load Factor in straight and level flight is +1.0g).

3.4.1 Limit 1.0+ ______________g, 1.0- ________________g.

3.4.2 Ultimate 1.0+ ____________g, 1.0- ________________g.

3.5 Plots of elevator required to trim versus lift coefficient and/or indicated airspeed at four center of gravity locations.

3.6 Minimum cable force in pounds at servo attachment points to produce structural limit load for any configuration; describe the configuration and structure involved.

3.6.1 Rudder ____________lb. at ______________________________

____

3.6.2 Aileron ___________lb. at ______________________________

____

____

3.6.3 Elevator __________lb. at ______________________________

____

____

3.7 Maximum allowable force in pounds at servo attachment point without overstressing control system.

3.7.1 Rudder ______________________ pounds.

3.7.2 Aileron _____________________ pounds.

3.7.3 Elevator ____________________ pounds.

3.8 Maximum rudder servo cable force in pounds at the servo attachment point required to hold the aircraft to zero rate of turn with wings level and full asymmetrical power. ______________ pounds.

3.9 Maximum servo cable force in pounds at the elevator servo attachment point required to land the aircraft with the center of gravity in its extreme forward position. ________________ pounds.

3.10 Static frictional force in pounds at the servo attachment points for primary controls. If friction is a function of control surface position, curves are required.

3.10.1 Rudder _______________ pounds.

3.10.2 Aileron ______________ pounds.

3.10.3 Elevator _____________ pounds.

3.11 Trim System

3.11.1 Type of trim system, (i.e., tab or surface, electrical or mechanical, etc.)

3.11.1.1 Rudder ______________________________

3.11.1.2 Aileron ______________________________

3.11.1.3 Elevator ______________________________

3.11.2 Plots of cable force in pounds and displacement in inches at the trim servo attachment points vs. trim surface motion in degrees relative to primary surface in specified flight configurations for the rudder, aileron and elevator trim systems, per attached Forms No. 2A and 2B.

3.11.3 Maximum cable travel in inches at automatic pilot trim servo attachment points.

3.11.3.1 Rudder ______________________________ inches.

3.11.3.2 Aileron ______________________________ inches.

3.11.3.3 Elevator ______________________________ inches.

3.11.4 Maximum allowable force in pounds at trim servo attachment points which will not overstress the control system.

3.11.4.1 Rudder ______________________________ pounds.

3.11.4.2 Aileron ______________________________ pounds.

3.11.4.3 Elevator ______________________________ pounds.

3.11.5 Static frictional force in pounds at the trim servo attachment points. If friction is a function of trim surface position, curves are required.

3.11.5.1 Rudder ______________________________ pounds.

3.11.5.2 Aileron ______________________________ pounds.

3.11.5.3 Elevator ______________________________ pounds.

3.11.6 If electric motors are used for manual trim, submit for all surfaces:

3.11.6.1 Motor Type.

3.11.6.2 Speed of trim surface.

3.11.6.3 Current and voltage.

3.11.6.4 Torque-speed curves, if available.

3.12 Speed Brake System

3.12.1 Location and type.

3.12.2 Type of actuator and speed of operation.

3.12.3 Details of any flap and/or throttle and/or landing gear interlocks.

3.13 Throttle Control System

3.13.1 Force in pounds at throttle servo attachment point required to move all throttles. ______________pounds.

3.13.2 Maximum allowable rate of throttle movement as a function of engine speed and/or power settings. __________ deg/sec.

3.13.3 Maximum throttle servo cable travel in inches at the servo attachment point. __________ inches.

4. Boost System Data

4.1 Classification and type of boost, (i.e., hydraulic or aerodynamic, type of tab, etc.)

4.1.1 Rudder ______________________________

4.1.2 Aileron ______________________________

4.1.3 Elevator ______________________________

4.2 Dynamic boost characteristics, including spring, inertia and damping loads reflected to the servo attachment points as functions of indicated airspeed; and amplitude ratio and phase of output travel vs. input travel as functions of input frequency and indicated airspeed. If response is non-linear supply sufficient curves to cover all ranges of input amplitudes.

4.3 For power boost systems:

4.3.1 Power boost schematics and descriptions with recommended automatic pilot tie-in.

4.3.2 Plots of control surface speed vs. valve displacement at no load.

4.3.3 Maximum hinge moment in lb-ft which can be developed by power boost.

4.3.3.1 Rudder __________________________ lb-ft.

4.3.3.2 Aileron __________________________ lb-ft.

4.3.3.3 Elevator __________________________ lb-ft.

4.3.4 Power boost total deadspot measured at control surface hinge line.

4.3.4.1 Rudder ______________________ degrees.

4.3.4.2 Aileron ______________________ degrees.

4.3.4.3 Elevator ______________________ degrees.

5. Aerodynamic Data

5.1 For clarity and completeness, all symbols used in this section will be defined, (NACA Terminology). All angles in radians unless specified in degrees.

X X-axis, positive forward.

Y Y-axis, positive towards the right wing.

Z Z-axis, positive towards the bottom of the airplane.

X Aerodynamic force along X-axis, positive forward pounds.

Y Aerodynamic force along Y-axis, positive towards right wing, pounds.

Z Aerodynamic force along Z-axis, positive towards bottom of airplane, pounds.

L Aerodynamic moment about X-axis, positive right wing down (Y to Z), foot-pounds.

M Aerodynamic moment about Y-axis, positive nose up (Z to X), foot-pounds.

N Aerodynamic moment about Z-axis, positive nose right (X to Y), foot-pounds.

u Linear velocity along Y-axis, positive forward, feet per second.

v Linear velocity along Y-axis, positive towards right wing, feet per second.

w Linear velocity along Z-axis, positive towards bottom of airplane, feet per second.

p Angular velocity about X-axis, positive right wing down (Y to Z), radians per second.

q Angular velocity about Y-axis, positive nose up (Z to X), radians per second.

r Angular velocity about Z-axis, positive nose right (X to Y), radians per second.

L Lift, perpendicular to flight path, positive towards top of airplane, pounds.

D Drag, parallel to flight path, positive towards rear of airplane, pounds.

T Thrust, positive forward, pounds.

W Weight, positive down, pounds.

V True airspeed along flight path, feet per second.

ϕ Angle of roll, positive right wing down (Y to Z), radians.

θ	Angle of pitch, positive nose up (Z to X), radians.
ψ	Angle of yaw, positive nose right (X to Y), radians.
$\dot{\phi}$	See definition of (p).
$\dot{\theta}$	See definition of (q).
$\dot{\psi}$	See definition of (r).
α	Angle of attack, angle between X-axis and the flight path in the plane of symmetry, positive nose up, radians.
γ	Flight path angle, angle between the flight path and the horizon, positive in climb, radians.
β	Angle of sideslip, lateral angle between X-axis and the flight path, positive flight path to the right, radians.
δ_e	Elevator angle, relative to the horizontal stabilizer, positive trailing edge down, radians.
δ_r	Rudder angle, relative to the fin, positive trailing edge left, radians.
δ_a	Aileron angle, relative to the wing, positive trailing edge down, radians. Subscript R or L denotes right or left aileron respectively. δ_a without subscript usually has the definition $\delta_a = \delta_{a_R} - \delta_{a_L}$.
δ_f	Flap angle, relative to the wing, positive trailing edge down, radians.
δ_B	Speed Brake deflection relative to closed position, radians.
δ_t	Tab angle, relative to the elevator, rudder or aileron, positive in the same sense, radians.
i_H	Stabilizer angle, relative to fuselage reference line, positive trailing edge down, radians (sometimes i_s or i_t is used for i_H).
S	Wing area, square feet.
b	Wing span, feet.
c	Wing chord, feet (usually Mean Aerodynamic Chord MAC or Mean Geometric Chord MGC).
S_v	Vertical Tail area, square feet.
l_v	Vertical Tail length, $\frac{1}{4}$ M.A.C. of the wing to $\frac{1}{4}$ M.A.C. of the vertical tail, feet.
S_H	Horizontal Tail area, square feet.
l_H	Horizontal Tail length, $\frac{1}{4}$ M.A.C. of the wing to $\frac{1}{4}$ M.A.C. of the horizontal tail, feet.

ρ	Air density, slugs per cubic foot.
q	Dynamic pressure, $\rho V^2/_2$
C_X	Longitudinal force coefficient. $C_X = X/Sq$
C_Y	Lateral force coefficient. $C_Y = Y/Sq$
C_Z	Normal force coefficient. $C_Z = Z/Sq$
C_l	Rolling moment coefficient. $C_l = L/Sqb$
C_m	Pitching moment coefficient. $C_m = M/Sqc$
C_n	Yawing moment coefficient. $C_n = N/Sqb$
C_L	Lift coefficient. $C_L = L/Sq$
C_D	Drag coefficient. $C_D = D/Sq$
T'_c	Thrust coefficient. $T'_c = T/Sq$
I_X	Moment of inertia about X axis, slug-ft^2.
I_Y	Moment of inertia about Y axis, slug-ft^2.
I_Z	Moment of inertia about Z axis, slug-ft^2.
I_{XZ}	Product of inertia about X and Z axes, slug-ft^2.
k_X	Radius of gyration about X axis, feet. $k_X = \sqrt{I_x/m}$
k_Y	Radius of gyration about Y axis, feet. $k_Y = \sqrt{I_y/m}$
k_Z	Radius of gyration about Z axis, feet. $k_Z = \sqrt{I_z/m}$
k_{XZ}	$k_{XZ} = \sqrt{I_{xz}/m}$
C_{I_X}	Moment of inertia coefficient about X-axis.

$$C_{I_X} = \frac{I_X}{Sqb}$$

C_{I_Y} Moment of inertia coefficient about Y-axis.

$$C_{I_Y} = \frac{I_Y}{Sqc}$$

C_{I_Z} Moment of inertia coefficient about Z-axis.

$$C_{I_Z} = \frac{I_Z}{Sqb}$$

$C_{I_{xz}}$ Product of inertia coefficient about X- and Z- axes.

$$C_{I_{xz}} = \frac{I_{XZ}}{Sqb}$$

H   Hinge moment, positive in sense to cause increasing deflection. Subscript denotes surface, H_e is elevator hinge moment, H_r is rudder hinge moment, etc., pound-feet.

S   Surface area aft of hinge line. Subscript denotes surface, S_e is elevator area, S_r is rudder area, S_f is flap area, etc., square feet.

b   Surface span. Subscript denotes surface, b_e is elevator span, b_r is rudder span, etc., feet.

$\bar{c}$ Surface average or root-mean-squared chord aft of hinge line (usually the latter). Subscript denotes surface, $\bar{c}_e$ is elevator chord, $\bar{c}_r$ is rudder chord, etc., feet.

C_h Hinge moment coefficient. $C_h = H/q\bar{c}^2b$ (sometimes $C_h = H/qSc$). Subscript denotes surface, C_{h_e} is elevator hinge moment coefficient, C_{h_r} is rudder hinge moment coefficient, etc.

I   Surface moment of inertia, Subscript denotes surface, I_e is elevator moment of inertia, I_r is rudder moment of inertia, etc., slug-ft^2.

m   Mass. $m = W/g$, slugs.

μ Relative density, $\mu = m/\rho Sb$

τ Time factor, $\tau = m/\rho sv$

D_b Non-dimensional differential operator. $D_b = (d/dt)b/2V$

D_c Non-dimensional differential operator. $D_c = (d/dt)c/2V$

p   Differential operator. $p = d/dt = (\,\dot{}\,)$, 1/seconds.

t   Time, seconds.

V_e Equivalent airspeed. $V_e = \sqrt{\sigma}\, V$

u' $\Delta u/V$

M   Mach number. $M = V/a$

h   Altitude above sea level, feet.

n   Load factor, aerodynamic force divided by airplane weight.

σ Angle between the apparent gravity and the plane of symmetry, positive for left ball on a ball-bank indicator.

α_V Angle of attack of the vertical tail, radians.

α_H Angle of attack of the horizontal tail, radians.

●   Angle of downwash at the tail, radians.

5.2 Aerodynamic Coefficients and Stability Derivatives

5.2.1 If coefficients and derivatives are not constant with airspeed, angle of attack, control surface deflection, flap configuration, sideslip angle, helix angle, Mach number, or altitude, provide plots describing the variation over the normal operating range of the aircraft.

5.2.2 Derivatives taken with respect to any angular rate may be presented in one of two ways. The non-dimensional operators may be employed to yield time-dimensionless derivatives, or the derivatives may be taken directly with respect to the angular rate, in which case they will have the units of seconds. For example:

$$C_{Y_{\dot\phi}} = \frac{\partial C_Y}{\partial \dot\phi} = \frac{b}{2V}\,\frac{\partial C_Y}{\partial\left(\frac{pb}{2V}\right)} = \frac{b}{2V}\,C_{Y_p}$$

In other words, $C_{Y_{\dot\phi}} \neq C_{Y_p}$. Similarly,

$$C_{l_{\dot\delta_a}} = \frac{\partial C_l}{\partial \dot\delta} = \frac{b}{2V}\,\frac{\partial C_l}{\partial\left(\frac{\dot\delta_a b}{2V}\right)} = \frac{b}{2V}\,C_{l_{D\delta_a}}$$

To avoid confusion of $p = \dot\phi$ with $p = \frac{d}{dt}$ and $q = \dot\theta$ with $q = \frac{\rho V^2}{2}$ it is desirable to use the time-dimensional derivatives when possible.

5.2.3 The following notes apply to sections 5.2.5, 5.2.6 and 5.2.7:

(1) These derivatives are required for dynamic analysis of fuselage flexibility. If body dynamics are negligible, the static effect may be included in the other derivatives.

(2) These derivatives are required if the horizontal stabilizer is adjustable.

(3) Separate control surface hinge moment data is necessary for dynamic analysis of aerodynamic boost systems. Static data is included in Forms 1 and 2.

(4) Here, sigma (σ) refers to the servo drive drum angle.

(5) Here, sigma (σ) refers to the sidewash angle at the vertical tail.

5.2.4 Flight Conditions Defined:

VARIABLE	SYMBOL	FLIGHT CONDITIONS				
		1	2	3	4	5
		Maximum IAS	High Altitude	Normal Cruise	Approach	Other (Name)
Altitude, feet	h					
True Airspeed, knots	V_{kts}					
Mach Number	M					
Center of Gravity, % MAC	C.G.					
Gross Weight, pounds	W					
Lift Coefficient	C_L					
Angle of Attack, deg.	α					
Flight Path Angle, deg.	γ					
Trim Stabilizer Angle, deg.	i_H					
Flap Position, deg.	δ_f					
Speed Brake Position, deg.	δ_B					

5.2.5 Radii of Gyration

RADIUS OF GYRATION	SYMBOL	FLIGHT CONDITIONS				
		1	2	3	4	5
About X- axis, feet	K_X					
About Y- axis, feet	K_Y					
About Z- axis, feet	K_Z					
For product of inertia, feet	K_{XZ}					

5.2.6 Lateral Stability Derivatives

VARIABLE	SYMBOL	FLIGHT CONDITION 1	2	3	4	5
$\partial C_Y/\partial\beta$	C_{Y_β}					
$\partial C_Y/\partial\dot\phi$ (sec)	$C_{Y_{\dot\phi}}$					
$\partial C_Y/\partial\dot\psi$ (sec)	$C_{Y_{\dot\psi}}$					
$\partial C_Y/\partial\delta_r$	$C_{Y_{\delta_r}}$					
$\partial C_Y/\partial\delta_a$	$C_{Y_{\delta_a}}$					
$\partial C_l/\partial\beta$	C_{l_β}					
$\partial C_l/\partial\dot\phi$ (sec)	$C_{l_{\dot\phi}}$					
$\partial C_l/\partial\dot\psi$ (sec)	$C_{l_{\dot\psi}}$					
$\partial C_l/\partial\delta_r$	$C_{l_{\delta_r}}$					
$\partial C_l/\partial\dot\delta_r$ (sec)	$C_{l_{\dot\delta_r}}$					
$\partial C_l/\partial\delta_a$	$C_{l_{\delta_a}}$					
$\partial C_l/\partial\dot\delta_a$ (sec)	$C_{l_{\dot\delta_a}}$					
$\partial C_n/\partial\beta$	C_{n_β}					
$\partial C_n/\partial\dot\phi$ (sec)	$C_{n_{\dot\phi}}$					
$\partial C_n/\partial\dot\psi$ (sec)	$C_{n_{\dot\psi}}$					
$\partial C_n/\partial\delta_r$	$C_{n_{\delta_r}}$					
$\partial C_n/\partial\dot\delta_r$ (sec)	$C_{n_{\dot\delta_r}}$					
$\partial C_n/\partial\delta_a$	$C_{n_{\delta_a}}$					
$\partial C_n/\partial\dot\delta_a$ (sec)	$C_{n_{\dot\delta_a}}$					
$(\partial C_L/\partial\alpha)_V$ (1)	$C_{L_{\alpha_V}}$					
$\partial\sigma/\partial\beta$ (1) (5)	σ_β					
$\partial\alpha_V/\partial\delta_r$ (1)	α_{δ_r}					