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DESIGN, DEVELOPMENT AND TEST CRITERIA - SOLID STATE PROXIMITY SWITCHES/SYSTEMS FOR LANDING GEAR APPLICATIONS

1. PURPOSE: The purpose of this AIR is to suggest specification, application, performance and validation criteria for solid state proximity switch systems used for environmentally severe applications on aircraft landing gear.

2. SCOPE: This document will examine the more important considerations relative to the utilization of "one piece", or integral electronics proximity switches, and "two piece", or separate sensor and electronics proximity switches, for applications on aircraft landing gear. In general, the recommendations included are applicable for other demanding aircraft sensor installations where the environment is equally severe.

3. DISCUSSION: Noncontact proximity switches have been used on some aircraft as landing gear control and indication limit switches since 1965. The types of proximity switches discussed in this document divide into two categories; integral electronic switches which operate on the principle of eddy current losses and separated sensor and electronic systems which use variable reluctance principles.

3.1 Integral Electronic Proximity Switch Characteristics and Performance: The following briefly describes the features and characteristics of the "one-piece" proximity switch.

- Installation - No separate electronic box required.
- Reliability - Experience has demonstrated an MTBF of 5,000 to 50,000 hours for each switch, depending on exposure and application.
- Maintainability - Integral proximity switches are generally not repairable.
- Sensing Range - .050 inch to .5 inch as a function of effective sensor area or sensor diameter.
- Target - Any conductive material; however, the actuation point varies with different materials. Ferromagnetic steel generally provides the maximum actuation range and should be utilized whenever possible.

3.1 (Continued)

- Temperature Range - -55°C to +71°C is normal. The upper limit can be extended to 125°C if the thermal interface is specified and controlled and adequately rated electrical parts are utilized.

- EMI Capability - No practical limitations except radiated susceptibility. Normal designs should be capable of operation in 20 volt per meter fields. Special designs which can operate in fields in excess of 300 volts per meter from 5 KHz to 4 GHz are presently in service. Aircraft HF, VHF and UHF transmitter bands should be tested.

- Shock - Current devices are capable of survival at up to 50g shock levels. This limitation is dictated by electronic component die attachment capability.

- Vibration - Depending upon mechanical mounting features and possible resonances of individual installations, normal designs are capable of 25 to 75 g's RMS equivalent vibration. Special designs are again limited only by the capability of the microcircuits and other components used in the design.

- Moisture/SWAMP Environment - The "SWAMP" is defined as a "severe wind and moisture problem" area. Experience has shown that moisture ingestion is the principal cause of premature failure of integral electronics proximity switches. Sealing integrity is severely tested by the rapid temperature and pressure changes associated with the SWAMP landing gear environment. It is strongly suggested that development and qualification test programs include the test parameters outlined in section 5. Production testing requirements should also consider the inclusion of a cycled high stress burn-in period ("Shake and Bake") to improve reliability by weeding out "infant mortality" failures.

3.2 Separate Electronics Proximity System Characteristics and Performance: Included here are the characteristics of the typical "two-piece" proximity switch system.

- Installation - Electronic modules, usually packaged together in a standardized (ATR) proximity electronics enclosure, are required to be located in an environmentally controlled aircraft area. Any required logic, output drivers and Built-In-Test (BIT) circuitry is usually included in the same enclosure. Point-to-point wiring, within the enclosure, is preferred for ease of maintenance and modification - if space constraints allow.

- Reliability - This type of system has demonstrated a field MTBF of 180,000 to 300,000 hours for each switch channel (one sensor together with its electronics module). The reason for the large improvement in reliability, over the one-piece switch, is that the electronics module is housed in a controlled aircraft environment and the sensor is a low impedance device that is inherently less sensitive to moisture ingestion.

3.2 (Continued):

- Maintainability - Electronics modules are repairable and replaceable without disturbing sensor installation/rigging. Sensors are non-repairable, but can be replaced without adjustment of the electronic module.

- Temperature Range - Sensor: Normally -55°C to 85°C or -65°C to +100°C. The range may, with special design effort, be extended to -200°C to +450°C. Electronic Module: -40°C to +71°C.

- Sensing Range - Similar to integral electronics unit.

- Target - Must be a ferromagnetic material such as 4130, 4340 and 17-4PH steel. For increased switching range and sensitivity, specialty high permeability alloys may be used. Inherently, this system has the capability to "see through" non-magnetic metals such as 300 series stainless steel and titanium.

- EMI Capability - Same as integral electronic switches except that care must be taken to ensure that radiated emissions requirements are met on the wires connecting the sensor to the electronics module. Sensor wiring is usually a twisted pair or triple for improved EMI rejection.

- Shock & Vibration - Sensor/Target: No practical limitations except with mounting features unique to individual designs. Switching repeatability is enhanced with rigid, well designed installations. Electronic Module: Normal electronics bay environment should not be exceeded without special care.

- Moisture/SWAMP Environment - The sensor in the separate electronics system is a low impedance device not inherently sensitive to moisture ingestion. However, moisture penetration can cause long-term deleterious effects resulting from corrosion and freeze-break failure.

4. SUGGESTED PRACTICES FOR DESIGN, DEVELOPMENT AND APPLICATION:

4.1 Materials:

- Standard parts or components which have a history of usage in similar applications are preferred for use in the design of proximity switch systems. This is not intended to preclude the use of new technology parts or components but only suggests that parts or components which have not been used in similar applications should be reviewed and tested carefully for adequate performance.

- All exposed metal parts must be of corrosion resistant material or protected to resist corrosion and structurally capable of surviving in the wheel well environment.

- Abutting dissimilar metals, as defined in MIL-STD-454 requirement 16, should not be used when exposed to wheel well conditions without special precautions.

4.1 (Continued)

- All potting or encapsulation compounds which are exposed to wheel well conditions must be hydrolytically stable. Suggested criteria are those of MIL-I-16923 for epoxies and MIL-S-23586 for silicones. Potting voids should be eliminated since they tend to collect contaminants and moisture. Hermetic techniques that eliminate exposed potting and encapsulation materials are preferred.

- In order to maximize reliability, the order of preference in the construction of the solid state electronic circuitry is as follows (the most preferred construction listed first and the least preferred last).

  a) monolithic microelectronic integrated circuits;
  b) thin film, thick film, or hybrid microcircuit devices;
  c) discrete parts.

- External components and surfaces should not be susceptible to, or damaged by aircraft fuel, hydraulic fluids, or cleaning agents.

4.2 Construction:

- Mounting - The sensor mounting means should prevent all relative motion between the switch and the structure to which it is attached. Proximity switches or sensors are not sensitive to mounting attitude. If units are to be installed within one inch of each other, care should be taken to ensure that the effect of one on the other is understood and acceptable. In addition, the effects of surrounding metal structure must be considered.

- Electrical Termination - Most switches or sensors include twisted "Pigtail" leads or shielded cables. The type and length of wire or cable is usually specified by the aircraft manufacturer. However, experience has shown that sensor wiring which meets the following guidelines, when located in the wheel well environment, will provide satisfactory service:

  1) Size: 20 gage minimum for twisted 2 or 3 wire cable.
  22 gage minimum for twisted, shielded and jacketed multi-wire cable.

  2) Wire: High strength copper alloy with silver plating is generally the preferred choice. Wire insulation systems that utilize flexible, homogenous modified teflon, of medium weight, is also generally preferred over light weight multi-wall stiff, springy constructions. MIL-W-22759 is a reasonable basic wire specification.

  "Wind-whip" and flexure during gear operation has created long term reliability problems with stiff, springy wire and cable in landing gear applications.

  The use of integral connectors on proximity sensors or switches in the wheel well may appear to offer maintainability advantages. However, a number of factors must be considered.

4.2 (Continued)

A connector can add cost and weight and increase the space required to mount a sensor. In addition, a connector adds series wire connections and increases the probability of electrical failure due to wire-to-wire and wire-to-ground leakage within the connector assembly, which is greatly exacerbated by the wheel well environment. The service history on some aircraft landing gear installations shows that cable-related failures account for a high percentage of switch problems. In these cases, use of integral connectors would probably have reduced the cost of ownership, by reducing the switch scrap rate.

It is recommended that the use of the integral connectors be decided according to the details of the individual installation. If the associated wiring can be adequately protected from corrosives, wind whip, and mechanical damage, use of a connector is probably not justified.

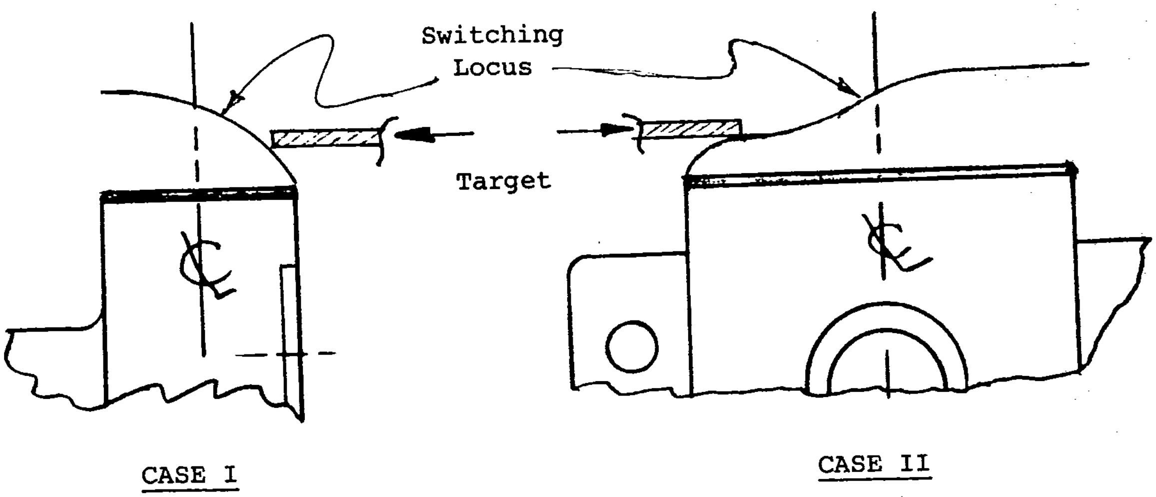
If integral connectors are specified, MIL-C-38999 - Series III Class "Y" or "N" - is suggested as the most appropriate choice for the sensor or switch in the wheel well environment.

- Case Grounding - The exterior finish of the switch or sensor housing should permit grounding of the switch to its mounting structure in accordance with MIL-B-5087. Grounding is normally required to enhance EMI resistance of the switch.

- All sensor wiring in a wheel well must be tightly secured and the use of flexible conduit for wire protection is recommended. Low point drains should be provided for all conduit or protective sheathing.

- Electrically shielded conduit is usually not required for "two-piece" systems unless aircraft configuration and/or mission specifications dictate otherwise. Special lightning protection and EMP (Electromagnetic Pulse) requirements are typical exceptions.

- Slide-by targets should present a straight-line sharp transition across the sensor face -- to maximize switching repeatability. With rectangular sensors, switching repeatability is enhanced if the target approaches and crosses the narrow dimension.



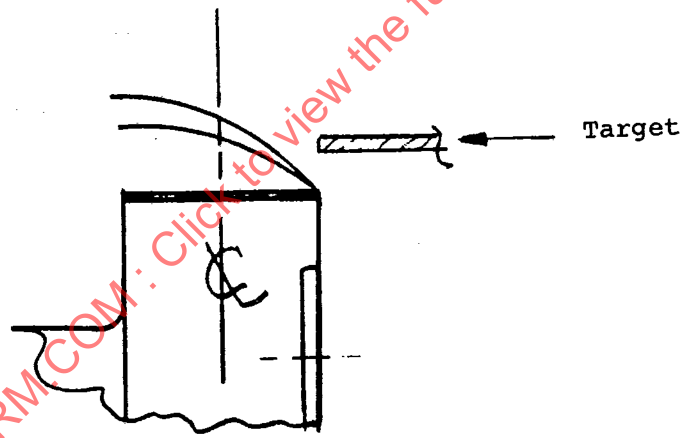
4.2 (Continued)

Note that when the target, in a slide-by mode, approaches the sensor across the width dimension (Case I) the switch locus curve is monotonic and switching repeatability, as a function of slight variations in target head-on gap, is maximized.

When the target is approaching the sensor across the long dimension (Case II) the flat area in the switching locus can cause large variations in switch point with minor changes in head-on gap. This characteristic is caused by the "two-pole" geometry of the rectangular sensor and the initial interaction of the target with a single pole.

Both poles of the sensor see the target at the same time in Case I.

- Targets should always be slightly larger than the sensor face to assure that minor misalignment does not affect switch point repeatability. In addition, target mounting designs must provide sufficient rigidity to control switch point repeatability.



REDUCED AREA TARGET EFFECTS

The upper locus shows the switching characteristic with a normal sized target (specified standard used for calibration).

The lower curve shows the switching response with a target that is half the width of the standard. Note that the "zero-gap" slide-by switch point is essentially the same for both targets but the head-on switch point is lowered for the reduced area target (approximately 20%). This results in a locus slope reduction and a decrease in switch point repeatability as a function on head-on spacing variations.

Round sensors exhibit the same general characteristic with reduced area targets.

TARGET MATERIAL EFFECTS

Two-Piece Sensors: If the standard target specified is fully annealed ferromagnetic steel (4130, 1020, etc) and all other parameters are unchanged, changing target material results in the following:

17-4PH (Annealed)	-	90% gap (approx)
17-4PH (RC 34/36)	-	98% gap (approx)
Hi Mu 80	-	110% gap (approx)

One-Piece Sensors: All ferromagnetic materials are approximately the same, in terms of gap, and non-ferromagnetic materials (aluminum, 300 series stainless, etc) will switch at approximately 50% of the standard ferromagnetic target gap - all other variables unchanged.

4.3 Target/Sensor Relationship: The target/sensor interaction in a Proximity Switch System is considered part of the switch system design. Figure 1 and 2 illustrate some general relationships applicable to most sensor applications. The following definitions apply:

Head-On Motion: The path of target motion is perpendicular to the sensor face and the target face is parallel to the sensor face.

Slide-By Target Motion: The path of the target motion is parallel to the sensor face on a common centerline and the target face and sensor face are parallel.

Rotate by: The radius path of target motion is parallel to the sensor face and the gap between the target and the sensor face is minimum (for a given center of rotation) only when the line from the center of target rotation to the target is collinear with a line perpendicular to the sensor face.

Differential Travel: The distance from the point of switch actuation to the point of switch deactuation (sometimes referred to as hysteresis or dead band).

Over-Travel: The distance from the point of closest specified switch actuation to the final nominal target position. The target should not be allowed to touch the sensor face but contact should not result in a false "TARGET AWAY" condition.

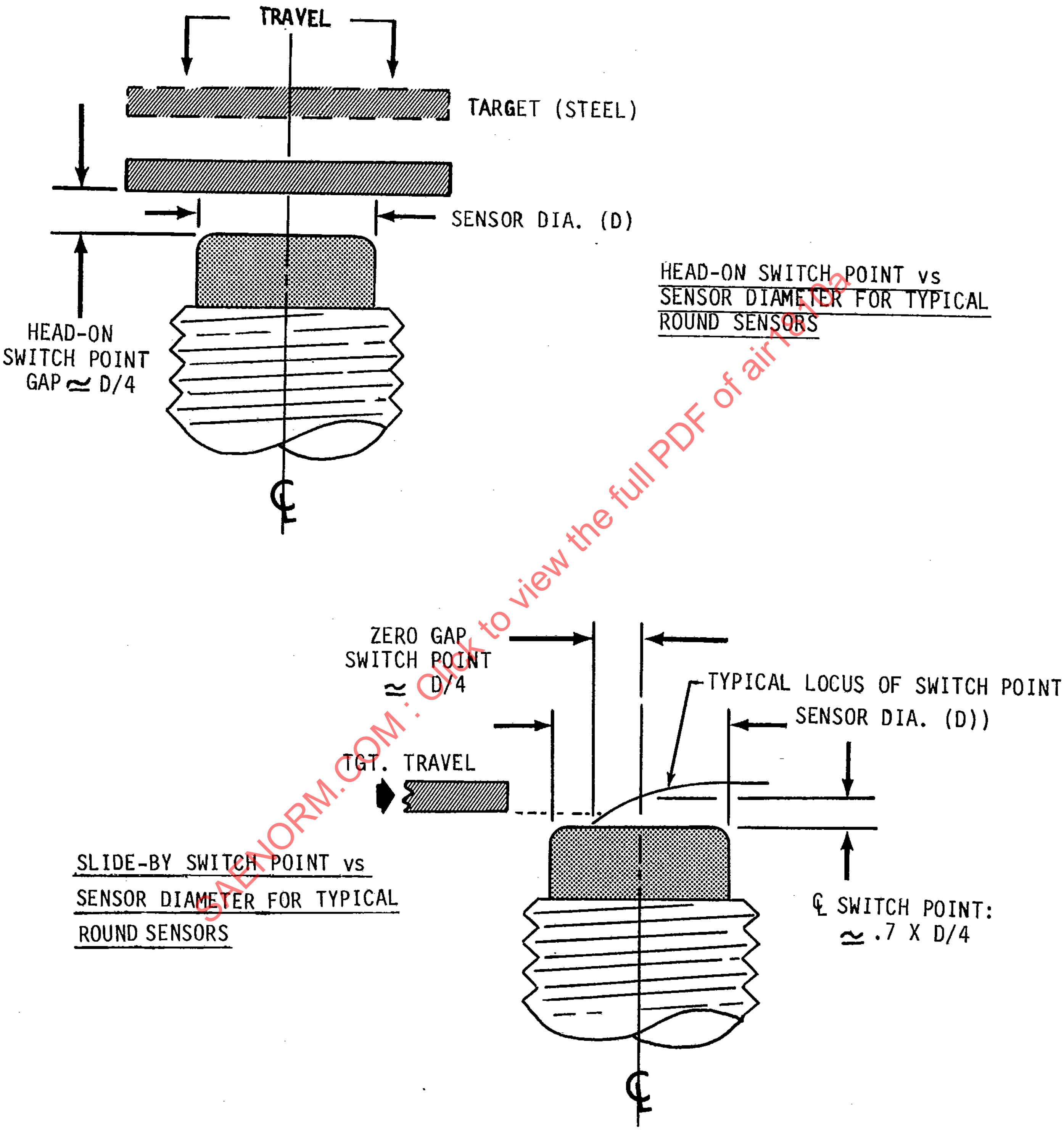
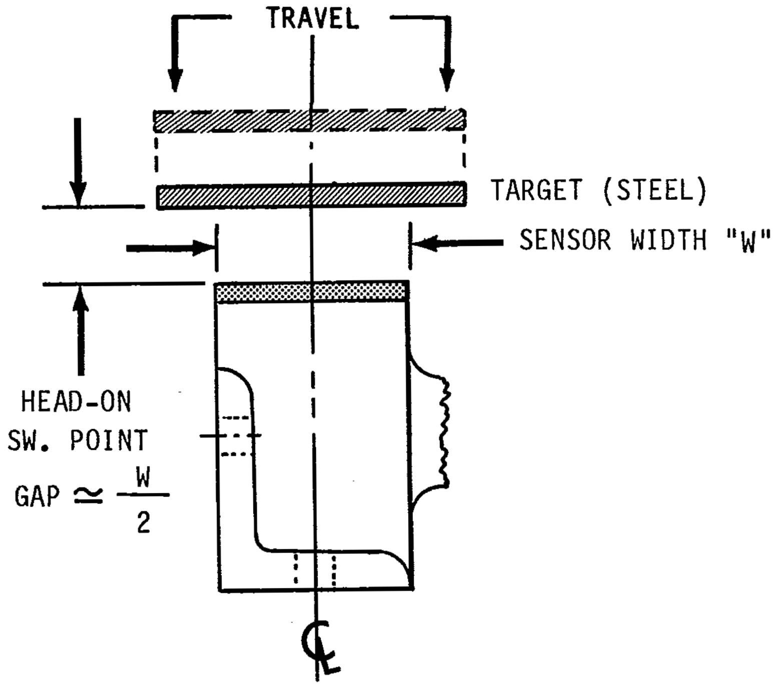
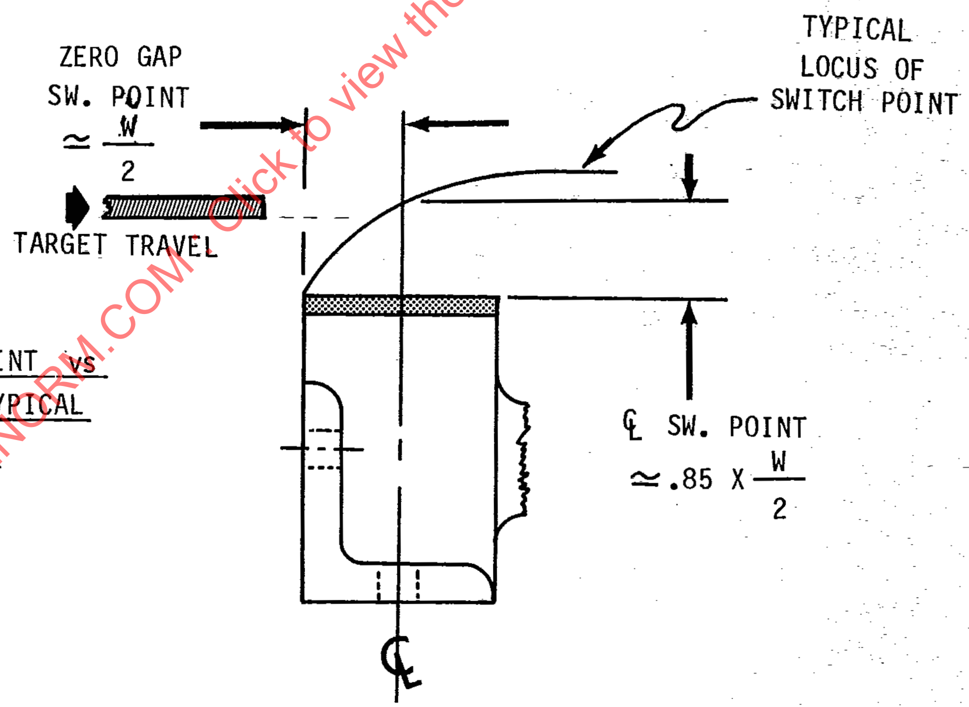

TRAVEL
TARGET (STEEL)
SENSOR DIA. (D)
HEAD-ON
SWITCH POINT
GAP ≃ D/4
HEAD-ON SWITCH POINT vs
SENSOR DIAMETER FOR TYPICAL
ROUND SENSORS
ZERO GAP
SWITCH POINT
≃ D/4
TYPICAL LOCUS OF SWITCH POINT
SENSOR DIA. (D))
TGT. TRAVEL
SLIDE-BY SWITCH POINT vs
SENSOR DIAMETER FOR TYPICAL
ROUND SENSORS
℄ SWITCH POINT:
≃ .7 X D/4

FIGURE 1



HEAD-ON SWITCH POINT vs WIDTH DIMENSION FOR RECTANGULAR SENSORS



SLIDE-BY SWITCH POINT vs SENSOR WIDTH FOR TYPICAL RETANGULAR SENSORS

NOTE: THIS IS THE RECOMMENDED SLIDE-BY MODE FOR MAXIMUM SWITCH POINT REPEATABILITY.

FIGURE 2

4.3 (Continued)

- Normal switch installation design should provide 40 to 60 percent over-travel (i.e.; if the minimum actuation point is 0.100 inch, nominal target rigging position should be 0.050 inch when the final target position is reached). Under no condition should over-travel be less than ten percent of minimum actuation distance under worst case target position conditions.

- In wheel well areas of the aircraft where icing may occur, the sensor/switch/target installation interface should take into consideration the forces on mounting brackets, targets and attachment hardware when the target motion will crush or sweep away ice. For installations of this type, slide-by or rotate-by target motion is preferred because it contacts the ice in shear and tends to sweep it away, rather than head-on target motion which traps and crushes the ice between the sensor/switch and target.

- Sensor lead exits should point down and drip loops and conduit low-point drains should be provided.

- The presence of contaminants such as oil, grease, fuels, solvents, ice, mud, dirt and carbon brake dust between the target and the sensor have no effect on the switch actuation properties.

4.4 Electrical Requirements:

- The switch/system must be designed and tested for operation at all voltage extremes anticipated. In addition, the switch/system must be capable of surviving high amplitude voltage spikes (transients) impressed on both the power lead (+28 Vdc) and the output lead. The specific requirements should be consistent with individual program environments. MIL-STD-704 is a reasonable guide.

- For normal applications, the switch should comply with MIL-STD-461 and the requirements defined via Methods CE03, CS01, CS02, CS06, RE02, RS02, and RS03 of MIL-STD-462.

- The output circuit performance must be specified for each separate requirement, or program, as to voltage drop, leakage current, current capability, short circuit capability, and the ability to survive reversal of power and output leads.

4.5 Maintainability Considerations: The switch or sensor installation should be designed so that, in the event of failure, a replacement part may be installed without adjustment of shims or other positioning hardware. This usually is accomplished by having separate attachment hardware for the positioning hardware (shims, etc.). In addition, in order to minimize system downtime, the attachment hardware for the switch or sensor should be easily accessible and removable (avoid riveted or welded installations).