AEROSPACE INFORMATION REPORT

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Superseding AIR1810C

(R) Installations/Applications, Development, and Test Criteria -
Solid State Proximity Switches/Systems for Landing Gear Applications

RATIONALE

This document revision update incorporates panel comments and current industry information and practices. Wording and phrasing are updated to align with an SAE Aerospace Information Report (AIR)-type document.

1. SCOPE

This document examines the most important considerations relative to the use of proximity sensing systems for applications on aircraft landing gear. In general, the information included are applicable to other demanding aircraft sensor installations where the environment is equally severe.

1.1 Purpose

The purpose of this SAE Aerospace Information Report (AIR) is to suggest specification, application, performance, and validation criteria for solid-state proximity sensing systems used for environmentally severe applications on aircraft landing gear.

1.2 Abbreviations

ARINC Aeronautical Radio, Incorporated

EMI Electromagnetic Interference

HASS Highly Accelerated Stress Screening

MTBF Mean Time Between Failures

OEM Original Equipment Manufacturer

SWAMP Severe Wind And Moisture Problem

SW Switch

TGT Target

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS1431 Solid Runway Deicing Anti-Icing Product

AMS1435 Liquid Runway Deicing/Anti-Icing Product

AMS1424/1 Deicing/Anti-Icing Fluid, Aircraft SAE Type I Glycol (Conventional and Non-Conventional) Based

AMS1424/2 Deicing/Anti-Icing Fluid, Aircraft SAE Type I Non-Glycol Based

AMS1428/1 Fluid, Aircraft Deicing/Anti-Icing, Non-Newtonian (Pseudoplastic), SAE Types II, III, and IV Glycol (Conventional and Non-Conventional) Based

AMS1428/2 Fluid, Aircraft Deicing/Anti-Icing, Non-Newtonian (Pseudoplastic), SAE Types II, III, and IV Non-Glycol Based

AIR5024 Landing Gear Switch Selection Criteria

2.2 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-C-85049 Connector Accessories, Electrical, Backshell, Environmental, Cable Sealing, Straight

MIL-I-16923 Insulating Compound, Electrical, Embedding, Epoxy

MIL-PRF-23586 Sealing Compound (With Accelerator), Silicone Rubber, Electrical

MIL-W-22759 Wire, Electric, Fluoropolymer-Insulated, FEP-PVF2, Lightweight, Silver-Coated, High Strength Copper Alloy Conductor, 600-Volt

MIL-STD-461 Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

MIL-STD-704 Aircraft Electric Power Characteristics

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

NOTE: Any obsolete or superseded MIL specs remain in this document for historical perspective reference. Use the revision applicable to the part configuration.

2.3 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

3. DISCUSSION

Non-contacting proximity switches have been used on some aircraft as landing gear control and indication limit switches since 1965. There are two kinds of proximity sensing systems in common use: proximity switches that have the switching electronics built into the sensing head and operate on the principle of eddy current losses or other proximity detection principles, and proximity sensors that use variable reluctance and are connected to remote switching electronics contained in a separate electronics module. Proximity sensors produce an output that is a function of the distance between the sensor and its target, and this characteristic can be used to provide the maintenance technician with help during rigging. Proximity switches, on the other hand, typically provide for legacy type units a bistate output: “target near” or “target far” or, for newer design units, a multistate output.

3.1 Integral Electronics Proximity Switch Characteristics and Performance

The following briefly describes the features and characteristics of the “one-piece” proximity switch.

a. Installation: No separate electronics module is utilized. Note that switches close to each other can affect each other

b. Reliability: Experience has demonstrated a high mean time between failures (MTBF) for each switch, depending on exposure and application. Contact the manufacturer for a predicted number.

c. Maintainability: Integral proximity switches are generally not repairable.

d. Sensing Range: From 0.050 to 0.100 inch (1.27 to 2.54 mm) for most types and longer ranges of 0.5 inch(12.7 mm) or more as a function of effective sensor area, sensor diameter, or use of a magnet target.

e. Target: Any conductive material, however, the actuation point varies with different materials. A dedicated target of Hymu 80 generally provides the most consistent actuation range and should be utilized whenever possible. A magnet target can provide longer sensing range.

f. Temperature Range: From -55 to 71 °C (-65 to +160 °F) is typical. The upper limits can be extended to 125 °C if the thermal interface is specified and controlled and adequately rated electrical parts are used.

g. EMI and Lightning Capability: Up to practical limitations of EMI circuitry contained in the integral electronics. Normal designs should be capable of operation in 20 V per meter fields. Latest proximity switch designs meet the latest aircraft program requirements. Check with the sensor/switch supplier for current EMI capability and to address EMI and lightning.

h. Shock: Current devices are typically capable of survival at up to 80 to 100 g shock levels.

i. Vibration: It is of the greatest importance that the mounting provisions account for the relative motion between the switch and target during exposure to vibration. The mounting hardware must be stiff enough to limit the change in the sensing gap to avoid the GA/GD zone with suitable margin when it is reacting to the forces imposed by the switch during acceleration. The target must also be robustly mounted. Each installation should be designed to limit relative motion in both the head-on and slide-by directions during deflection of the structure to prevent false indications. Depending upon mechanical mounting features and possible resonances of individual installations, normal designs are capable of withstanding 25 to 75 g RMS equivalent vibration. Special designs are limited only by the capability of the microcircuits and other components used in the design. Careful consideration should be made of any mounting bracket to check combined sensor/switch with bracket resonances and Q’s (Q = quality factor/transmissibility, a ratio of vibration at resonance versus at baseline, A Q of 2 = twice the vibration level at resonance) to not exceed ratings. Test vibration in a setup that duplicates aircraft installation to a practical extent, including a mating connector with backshell and cable type, and run to the first tie down location.

j. 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 non-hermetic sealed 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 a hermetic sealed switch be used and 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, such as HASS, 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 sensor system.

a. Installation: Electronics modules, usually packaged together in a standardized ARINC 600 proximity electronics enclosure or a remote data concentrator (RDC), located in a suitable aircraft area. Any required logic, output drivers, and built-in-test (BIT) circuitry are usually included in the same enclosure. Note that sensors close to each other can affect each other.

b. Reliability: This type of system has demonstrated a field very high field MTBF for each proximity sensor and 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. Contact the manufacturer for a predicted MTBF number.

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

d. Temperature Range:

   1. Sensor: Normally -55 to 85 °C (-65 to +185 °F) or -65 to +100 °C (-85 to +212 °F).

   2. Electronic Module: Typical operating is -40 to +71 °C (-40 to 160 °F) with consideration for startup after airplane cold soak, as agreed with the system OEM.

e. Sensing Range: Similar to integral electronics unit, nominally 0.050 to 0.100 inch (1.27 to 2.54 mm) with longer ranges to 1 inch (about 40 mm) or more possible by either using a magnet target or a larger diameter sensor.

f. Target: Typically, a ferromagnetic material, such as 4130, 4340, or 17-4PH steel. For increased switching range and sensitivity, specialty high permeability alloys, such as Hy Mu80, are preferred. This system has the inherent capability of “seeing through” nonmagnetic metals, such as low permeability 300 series stainless steel and titanium alloy. Magnet target technology can provide a longer range when used with a suitable sensor.

g. EMI/Lightning Capability: The 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 shielded, twisted pair, or triple, for improved EMI rejection. Route the wiring and provide grounding so the EMI or lightning threat is applied as a common mode to the electronics. Contact the sensor supplier for detailed information to meet a particular program EMI/lightning requirement. Each installation should be considered separately as previous successful wiring may not be adequate for a new installation.

h. Shock and Vibration:

   1. Sensor/Target: As with proximity switches, it is of great importance that the mounting provisions account for the relative motion between the sensor and target during exposure to vibration. The mounting hardware must be stiff enough to limit the change in the sensing gap to remain within the Ga/GD zone with suitable margin when it's reacting to the forces imposed by the switch during acceleration. The target must also be robustly mounted. Each installation should be designed to limit motion in both the head-on and slide-by directions during deflection of the structure so that false indications are prevented. No practical limitations exist except with mounting features that are unique to individual designs. Switching repeatability is enhanced by rigid, well-designed installations. Careful consideration is made of any mounting bracket to check combined sensor/switch with bracket resonances and Qs to not exceed ratings. Test for vibration in a setup that duplicates as much as practical aircraft installation, including mating connector with backshell and cable type, and run to first cable tie-down point.

   2. Electronics Module: The normal electronics bay environment is typically not exceeded without special care.

i. Moisture/SWAMP Environment: Moisture penetration can cause long-term deleterious effects resulting from corrosion and freeze-break failure. For these reasons, a hermetic seal sensor is best.

4. TYPICAL PRACTICES FOR DESIGN, DEVELOPMENT, AND APPLICATION

4.1 Materials

a. All exposed parts are made of corrosion resistant or protected material to resist corrosion and structurally capable of surviving in the wheel well environment. Nonmetallic materials should be resistant to the effects of ozone and ultraviolet radiation, as well as fluids such as phosphate ester hydraulic fluid. Modern designs are of all metal hermetic seal welded construction. Any materials exposed to deicers should have resistance to AMS1431 and AMS1435 runway deicers and AMS1424/1, AMS1424/2, AMS1428/1 and AMS1428/2 airplane deicers. Most, if not all, runway deicers utilize alklai metal (salts) sodium and potassium. These alklai metals significantly increase electrical conductivity. AMS1424/2 and AMS1428/2 airplane deicers are also composed of alkali metals. The use of cadmium plating on electrical connectors needs to be avoided. Alkali metal runway deicers rapidly deteriorate/consume cadmium. Refer to FAA Airworthiness Directives 2002-16-03 and 2005-18-23.

b. Abutting dissimilar metals are not used when exposed to wheel well conditions without special precautions.

c. Potting and encapsulation type designs are not suitable for new programs. For historical reference, compounds that are exposed to wheel well conditions are designed for protection against moisture. Potting, such as those of MIL-I-16923 for epoxies and MIL-PRF-23586 for silicones, are often used for these applications. Potting voids are not allowed since they tend to collect contaminants and moisture. Hermetic-sealed housing techniques that eliminate exposed potting and encapsulation materials are preferred.

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

   1. Monolithic microelectronic integrated circuits.

   2. Thin film, thick film, or hybrid microcircuit devices.

   3. Discrete parts.

e. External components and surfaces are designed to not be damaged by aircraft fuel, hydraulic fluids, disinfectants, deicers, or cleaning agents.

4.2 Construction

a. 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 effects of one on the other are understood and acceptable. In addition, the effects of surrounding metal structure must be considered. For round sensors, the sensor body, when applicable, and the nuts used to attach the sensor to the aircraft structure are best provided with lockwire holes. A groove in the threaded portion of the barrel in conjunction with using a tanged washer will prevent rotation when mounting nuts are tightened.

b. Electrical Termination: Most switches or sensors include twisted “pigtail” leads or shielded cables. The aircraft manufacturer usually specifies the type and length of wire or cable. However, experience has shown that sensor wiring that meets the following guidelines, when located in the wheel well environment, will provide satisfactory service:

   1. Size:

      (a) 20 gauge minimum for twisted 2- or 3-wire shielded cable.

      (b) 22 gauge minimum for twisted, shielded, and jacketed multi-wire cable.

2. Wire: High-strength copper alloy with silver plating is generally preferred. Wire insulation systems that use flexible, homogenous modified Teflon of medium weight are also generally preferred over lightweight multi-wall, stiff, springy constructions. MIL-W-22759 is a reasonable, basic wire specification. For installations where the sensor harness has to be very flexible (e.g., routing the sensor wire in conduits that fold with a side brace mechanism or that are routed over the torque link apex), a wound (wrapped) wire insulation provides much better flexibility and endurance than extruded insulation systems.

c. “Wind-whip” and flexure during gear operation have created long term reliability problems with stiff, springy wire and cable in landing gear applications.

d. 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 are often considered.

1. 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 owing to wire-to-wire and wire-to-ground leakage within the connector assembly, which is greatly exacerbated by the wheel well environment. The service histories on some aircraft landing gear installations show that cable-related failures account for a high percentage of switch problems. The use of connectors for sensors on landing gear installations is typically avoided. In the wheel wells, connectors are only used where they are not directly exposed to spray or driving rain, and they are oriented horizontally to avoid the collection of moisture and contamination in open cavities of the connector.

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

3. If integral connectors are specified, MIL-C-85049 Series III or MIL-DTL-38999 Series III or MIL-DTL-83723 or EN29917 are suggested as the most appropriate choice for the sensor or switch in the wheel well environment.

4. The connector keyway should be “clocked” rather than oriented randomly. Same size connectors/receptacles in the same area shall feature different keyway orientations for mistake proofing.

e. Case Grounding: The exterior finish of the switch or sensor housing should permit grounding of the switch to its mounting structure. Grounding is normally required to enhance EMI resistance of the switch.

f. All sensor wiring in a wheel well must be tightly secured and the use of flexible conduit for wire protection is normally used. Sensor lead exits should point down, and drip loops and low-point drains should be included for wiring and conduit or protective sheathing.

g. Slide-by targets 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 width dimension.

h. 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.

i. 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. The “two-pole” geometry of the rectangular sensor and the initial interaction of the target with a single pole cause this characteristic.

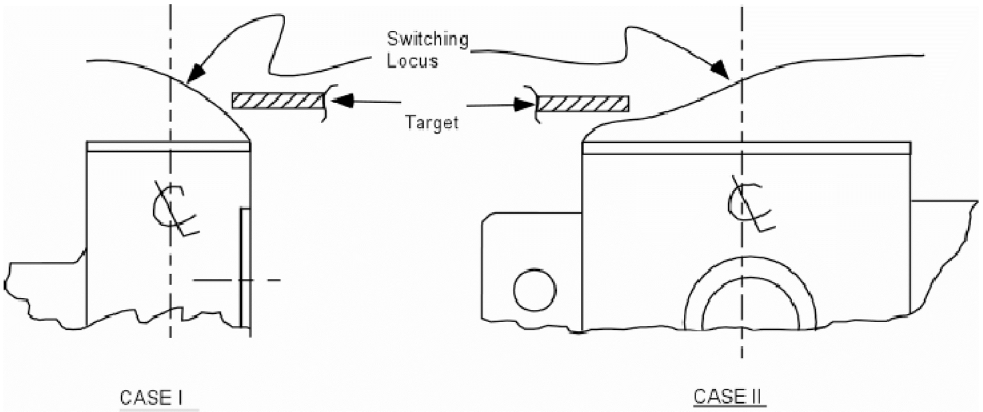

Figure 1 - Slide-by target

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

k. Targets are always slightly larger than the sensor face to ensure that minor misalignment does not affect switch point repeatability. In addition, target mounting designs provide sufficient rigidity to control switch point repeatability.

l. The upper locus shows the switching characteristic with a normal sized 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 of head-on spacing variation.

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

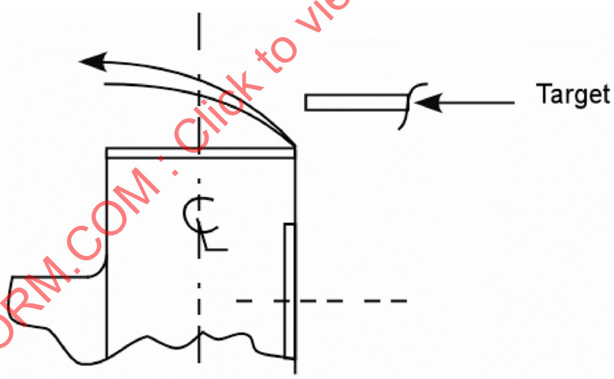

Figure 2 - Reduced area target effects

4.3 Target Material Effects

All ferromagnetic materials are approximately the same in terms of gap actuation point, and highly conductive materials, such as aluminum, will switch at approximately 50% of the standard ferromagnetic target gap if all other variables are unchanged. For example, if actuation point is 0.100 inch (2.54 mm) with a ferromagnetic target, then typical actuation point with aluminum or other highly conductive target is about 0.05 inch (1.27 mm).

4.4 Target/Sensor Relationships

a. The target/sensor interaction in a proximity switch system is considered as part of the switch system design. Figures 3 and 4 illustrate some general relationships applicable to most sensor applications. The following definitions apply:

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

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

3. 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 at a 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.

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

5. Overtravel: The distance from the point of closest specified switch actuation to the final nominal target position. Normally, the target is not allowed to touch the sensor face and inadvertent contact cannot result in a false “TARGET FAR” condition.

b. Normal switch installation design provides 40 to 60% overtravel (i.e., if the minimum actuation point is 0.100 inch [2.54 mm], nominal target rigging position of 0.050 inch [1.27 mm] when the final target position is reached). Under no condition would overtravel be less than 10% of minimum actuation distance under worst-case target position conditions. A standard rigging tolerance of ±0.010 inch (0.254 mm) is used for both round sensors and rectangular sensors whenever possible. Experience shows that the use of a tighter tolerance to reduce hysteresis in the switching region can lead to difficulties in rigging and increased probability of false indication.

c. In wheel well areas of the aircraft where icing may occur, the sensor/switch/target installation interface takes 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 motion is preferred because it contacts the ice in shear and tends to sweep it away, rather than head-on target motion that traps and crushes the ice between the sensor/switch and target.

d. In landing gear door applications, if the pressurization of the fuselage or other forces such as weight on wheels tends to affect the target/sensor gap, either the entire target/sensor installation is isolated from differential movement (preferred) or a spacer on a spring-loaded target is used to control the gap. The stroke of the spring-loaded target is designed so that it can follow only the deflections that occur during fuselage pressurization.

e. Where dual targets are used for redundant signals (e.g., weight on wheels), both target and both sensor mountings are independent so that if one target/sensor gets damaged, it does not disable the other target/sensor.

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

g. Target shape is commonly round or rectangular, but may be any shape suitable for the installation. Target size ideally takes into account the excitation field of the sensor and any nearby structure “side metal” effects when characterizing actuation and de-actuation points. Any installation not using the standard round target could be mocked up by the sensor supplier to properly characterize the installation Ga/Gd curves. Include simulated mounting brackets and other sensors and housing bodies if concerned with their effects.

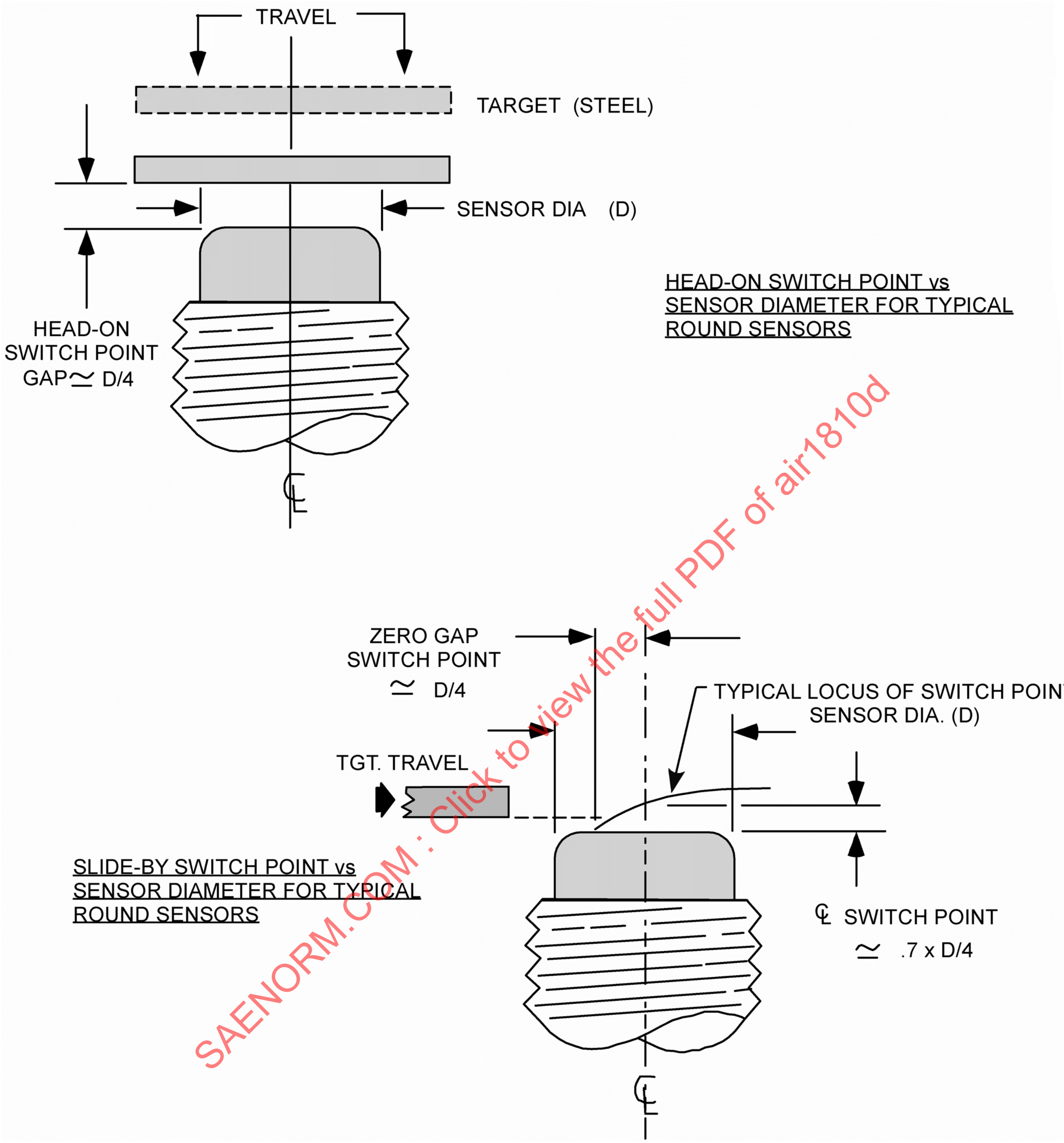

Figure 3 - Round sensor target relationship

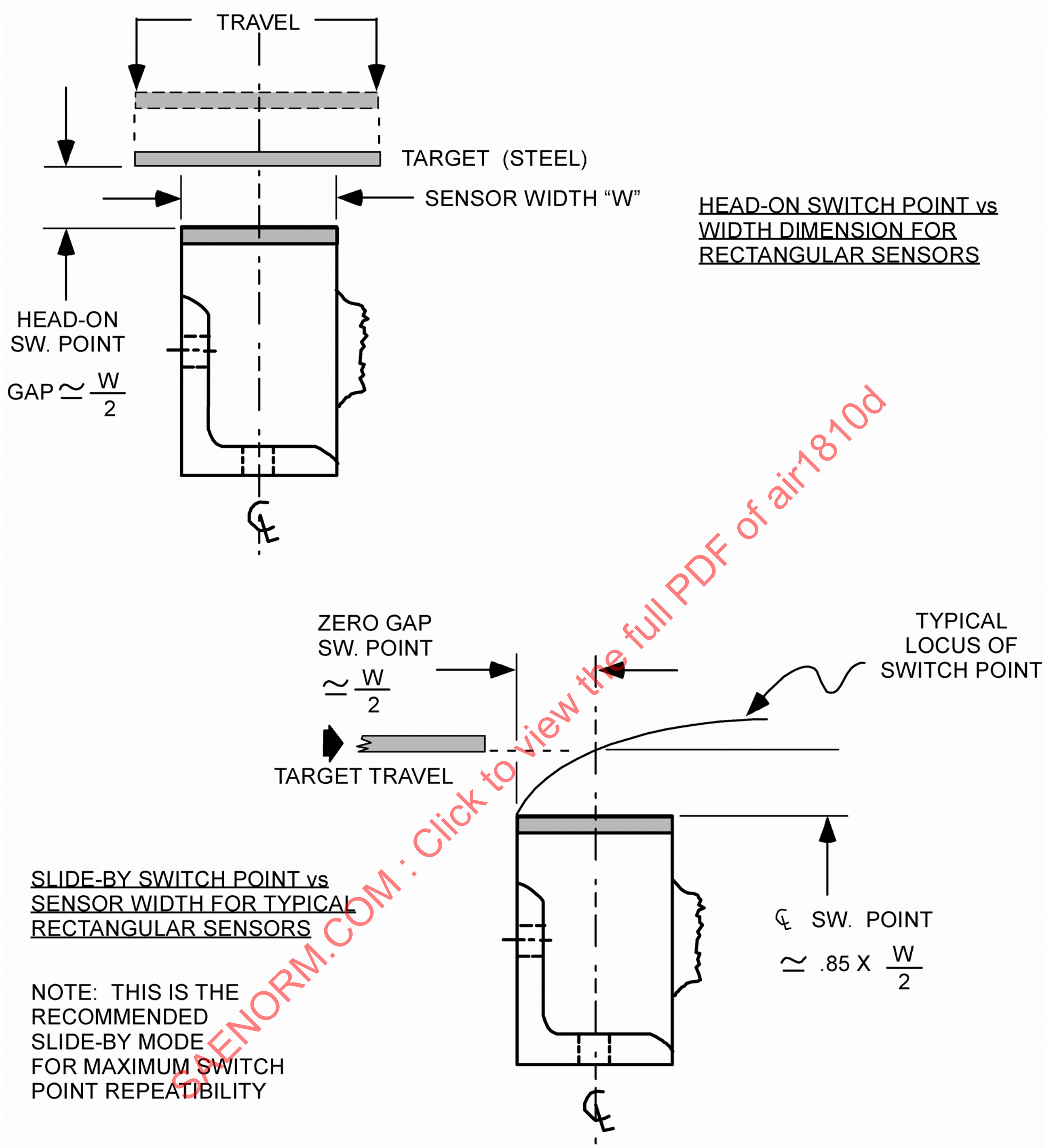

Figure 4 - Rectangular sensor target relationship

4.5 Electrical Requirements

a. The switch/system is ideally designed and tested for operation at all voltage extremes anticipated. In addition, the switch/system is typically capable of surviving high amplitude voltage spikes (transients) impressed on both the power lead (+28 V DC) and the output lead. The specific requirements are to be consistent with the individual program environments. MIL-STD-704 is a reasonable guide or the applicable airframe electrical power specification.

b. For normal applications, the switch is designed to comply with MIL-STD-461 or the applicable airframe electromagnetic interference specification.

c. The output circuit performance is ideally 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.

4.6 Maintainability Considerations

a. The switch or sensor installations are best designed so that, in the event of failure, a part replacement may be made without adjustment of shims or other positioning hardware. This is usually accomplished by attaching the positioning hardware to structure independently of the sensor or switch fasteners. In order to minimize system downtime, the attachment hardware for the switch or sensor should be easily accessible and removable: riveted or welded constructions should be avoided. Where dual targets are used for redundant signals (e.g., weight on wheels), both target and both sensor mountings should be independent so that if one target/sensor gets damaged, it does not disable the other target/sensor.

b. For separate electronic proximity systems, where the electronics modules are packaged in an electrical enclosure and located in an aircraft electronics bay, the following requirements are typically considered:

   1. The electronics enclosure is designed so that the individual circuit cards are accessible without removing the enclosure from the rack if they are to be used as LRUs (line replaceable units). Static discharge cautionary warnings are included on all removable covers.

   2. Individual cards are designed to be easily removed from the enclosure, and also designed so as to preclude damage due to handling and static discharge. Cards include keyed connectors. Card-edge type connections are avoided.

c. A BIT subsystem, if included, is able to confirm operational status of the entire system or, in the event of a failure, identify the failed LRU (card or sensor). There are no single component failure modes in the BIT subsystem that can permanently affect function of the operational subsystems. In the air mode, the BIT system cannot be capable of energizing output drivers.

d. The use of an in-flight continuous BIT system that would detect faults that may not show up on ground tests is often considered. When the electronics module generates a flight deck effect, such as a “caution” or “warning” message, any results can be stored in nonvolatile memory so that ground maintenance crews can retrieve them, even after power removal.

e. BIT systems can include maintenance aids, such as “rigging help” or “trend monitors.” Rigging help is used to confirm the correct rigging of sensor installations. Trend monitors are used during preventive maintenance when a “target too near” or “target too far” indication is provided with the target in the near position. This feature is not used where deflections under normal load (fuselage pressurization) could generate nuisance fault messages. The incorporation of these maintenance aids into the electronic module is preferred to the use of ground test equipment (see 4.7) because the approach precludes the need to undo connectors or open junction boxes.