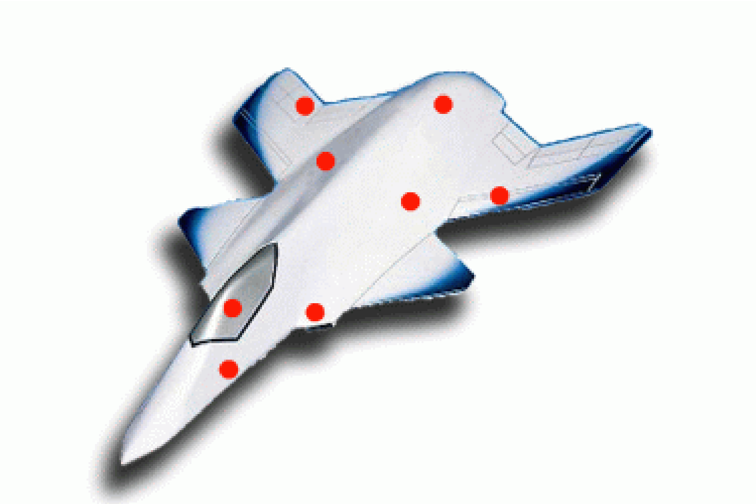
UAV Displacement Sensors

Reducing Cost of Ownership



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Abstract

Besides the lack of a human on board, UAVs have a number of differences relative to manned aircraft. A key difference is that UAV low system cost can be a more important design objective than high MTBF figures as compared to manned aircraft.

Manned aircraft, with obvious reason, use displacement sensors that can last 20 or 30 years without replacement or maintenance. These sensors are robust, often include redundant outputs, and give excellent performance. They

are also expensive and require expensive supporting electronics.

Many UAVs have less demanding lifetime, flight profile, and environmental requirements than manned aircraft. UAVs are also generally more focused on small size and low mass than manned aircraft. As such, many UAV components, including displacement sensors, have a different optimum set of specifications.

This paper will look at the displacement sensor applications in aircraft including flight controls, landing gear, environmental control systems, and bay doors. The differences in displacement sensor requirements for manned and unmanned aircraft will be explored including mass, MTBF, ease of use, and cost. The paper will then review the total cost of ownership of a generic displacement sensor. The conclusion will be a comparison of various displacement sensor types in regards to capabilities and total cost of ownership. The reader will come away with an understanding of the tradeoffs between cost and performance as related to displacement sensors.

Introduction

As unmanned aerial vehicle (UAV) developments take a larger role in the aerospace industry, we may ask ourselves "What is the main benefit of a UAV?" An assertion of this paper is that the main benefit of a UAV is to reduce cost relative to the manned aerial vehicle alternative. "Cost" may be a "soft" cost such as human risk or a "hard" cost such as reduced environmental control requirements or reduced redundancy requirements.

With this assertion in mind, we will review how displacement sensor selection can reduce both UAV acquisition cost and UAV operational cost. Specifically, we will:

- review aircraft displacement sensor applications
- examine differences in manned and unmanned vehicle requirements
- discuss what contributes to sensor lifecycle cost
- review sensor technologies and costs

A few notes before we begin:

1. While displacement sensors will be the focus, the material presented may be applied to a broad range of UAV sensors and subsystems.
2. We may raise more questions than answers. However, knowing which questions to ask is often half the battle in getting to a decision.
3. In the interest of brevity and consistency, we will use the acronym "MAV" for the term "manned aerial vehicle".
4. The paper will make a number of generalizations about UAVs. Given the diverse nature of aircraft in general and specifically UAVs, these generalizations will not be true for all UAVs.

With these preliminaries out of the way, let's get down to business.

Terminology

For ease of communication, we refer to transducers and sensors as being the same. It is generally irrelevant whether you are using a position sensor or transducer. The goal of both is the same - to find out where something is.

We are focused on displacement sensors that monitor movement from one position to another for a specific distance or angle. As such, we are focused on continuous-sensing devices versus discrete-sensing devices such as proximity sensors that signal a critical distance using an on/off output. We will not address sensors that track position using technologies such as GPS and inertial measurement systems (see Figure 1).

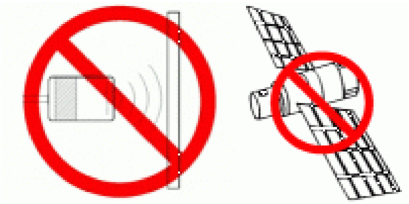
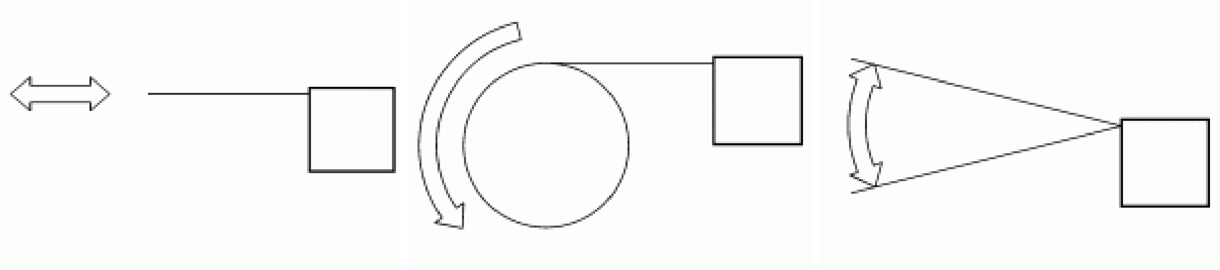


Figure 1 - Proximity sensors and positioning systems such as GPS will not be covered.

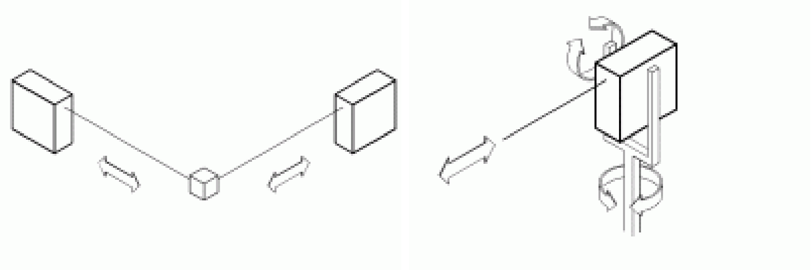
Displacement Sensing Types

Displacement sensing can be categorized into 5 categories related to the geometry of motion being sensed (see Figure 2):

- linear
- rotary: motion greater than 360°
- angular: a special case of rotary motion limited to 360° or less
- 2D: flap
- 3D: aeroelastic (warping) wing



Linear Rotary (> 360°) Angular (< 360°)



Two Dimensional (2D) Three Dimensional (3D)

Figure 2 - Displacement sensing categories

Displacement Sensing on Aircraft

Often hidden from view, displacement sensors are quite prevalent in both UAVs and MAVs. A few examples are below and in Figures 3 and 4:

- Pilot Controls
- Flight
- Control Surfaces and Actuators
- Landing Gear, Munitions, Speed Brake Doors
- Brake and Steering Systems
- Fuel and Engine Controls
- Environmental Controls

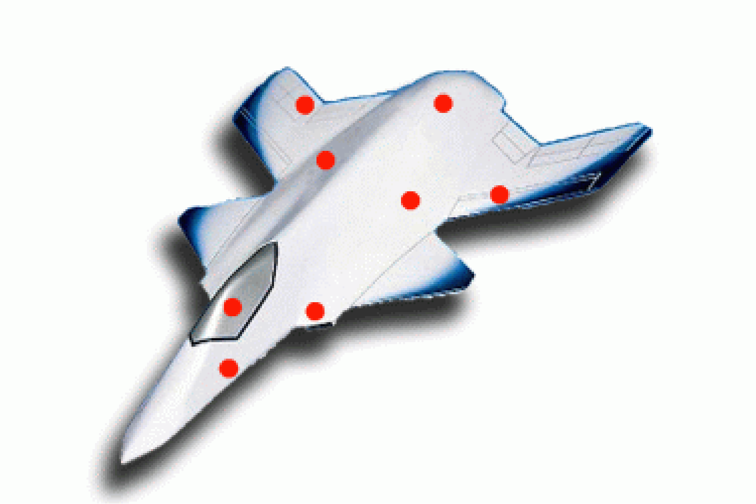
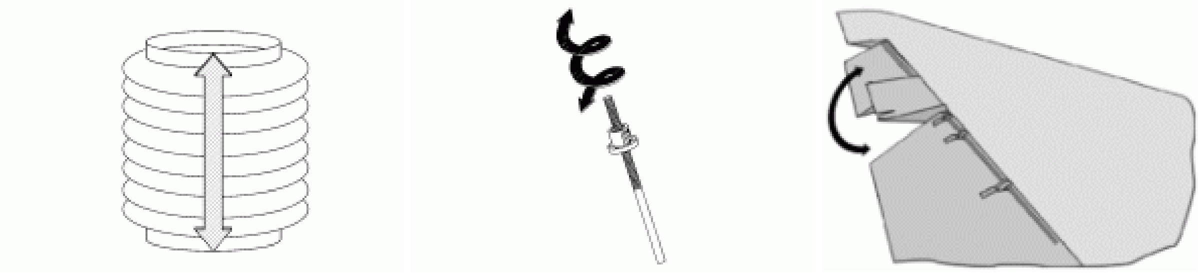
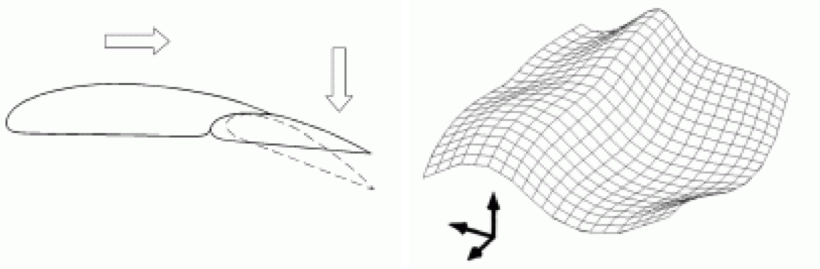


Figure 3 - Displacement sensors are prevalent on MAVs and UAVs



Linear: Bellows
Rotary: Ballscrew
Angular: Flight Controls



2D: Flap
3D: Aeroelastic (Warping) Wing

Figure 4 - Aircraft displacement sensing examples

Aircraft displacement sensing generally involves linear, rotary, and angular. In situations where two- and three-dimensional sensing is required, two or three displacement sensors are often used.

UAV/MAV Differences

Beyond the obvious presence of a human, UAVs and MAVs have key differences as related to the selection of components in general and specifically displacement sensors. These differences are in five areas: cost, size, weight, flight duration, lifetime, and expendability. Let's examine each difference.

Cost - As asserted previously, UAVs must be produced at a lower cost if they are to be successful.

Size - UAVs are generally much smaller than MAVs doing the same job. Much of this size difference is due to the lack of a pilot and supporting systems on the UAVs (see Figures 5 and 6).

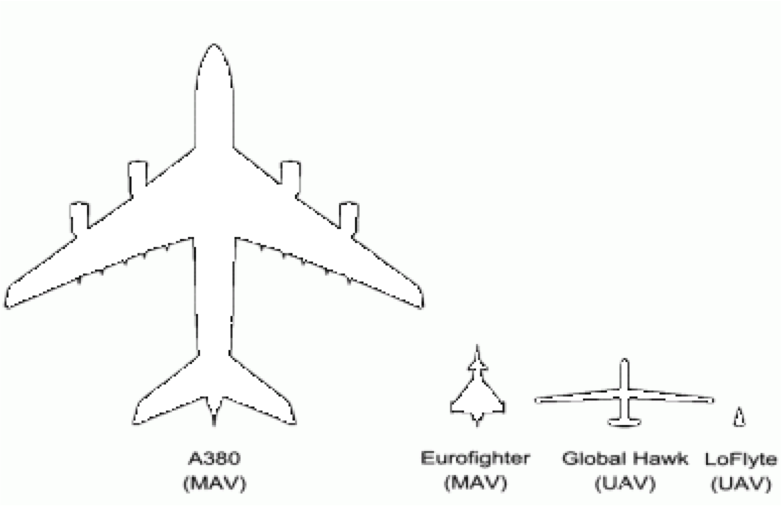


Figure 5 - Graphical representation of MAV versus UAV size

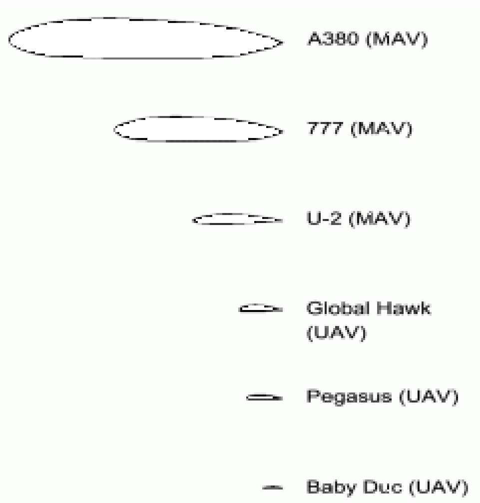


Figure 6 - Wing size comparison of MAVs versus UAVs

Weight - The cost, size, and flight duration differences map to a requirement for lower weight for UAVs. In turn, the low weight synergistically allows for smaller size and lower cost.

Flight Duration - While we are early in the UAV "game", it is possible the flight duration of a typical UAV will be less than that of a MAV. Why? Initially, the reason will be due to flight restrictions. Later, flight durations will generally be less due to the requirement of low-cost that creates add-on requirements of low weight and small size. While certainly there will be UAVs with flight durations exceeding current MAVs, these UAV applications, typically in the reconnaisance and communications area, will have a unique set of requirements.

Lifetime - Changing requirements, changing technologies, and a dynamic industry indicate UAVs will have lower lifetime requirements than MAVs. In addition, a lower-cost vehicle does not need to perform as long to reach a "break even" point. Therefore, shorter payback periods will likely motivate users to change to new platforms sooner than is the case with MAVs.

Expendability - The probably reduced risk of human life loss associated with UAVs makes them inherently more expendable than MAVs. In addition, the lack of human allows UAVs to operate in extreme-danger environments adding to the requirement that they be more expendable.

Implications of UAV/MAV Differences

What implications do the differences between UAVs and MAVs have for displacement sensor selection? Optimum UAV displacement sensors will be:

- small sized
- low weight
- simple and low power requirements to reduce support equipment cost and weight requirements
- affordable to acquire and use (total lifecycle cost)

Let's look more closely at the concept of total lifecycle cost as applied to sensors.

Total Lifecycle Cost

The lifetime cost of a sensor involves more than the initial purchase cost. By looking at the total cost of ownership, an optimum purchase decision can be made specific to your application.

If you purchase a car, the initial purchase price may only be 60% of the total lifetime cost of the vehicle. Gas, oil, repairs, insurance, maintenance, taxes, license fees, and other costs can exceed the initial purchase price over a 5- to 10-year typical vehicle lifetime.

If you purchase a PC, the initial purchase price may only be 10% of the total lifetime cost of the computer.

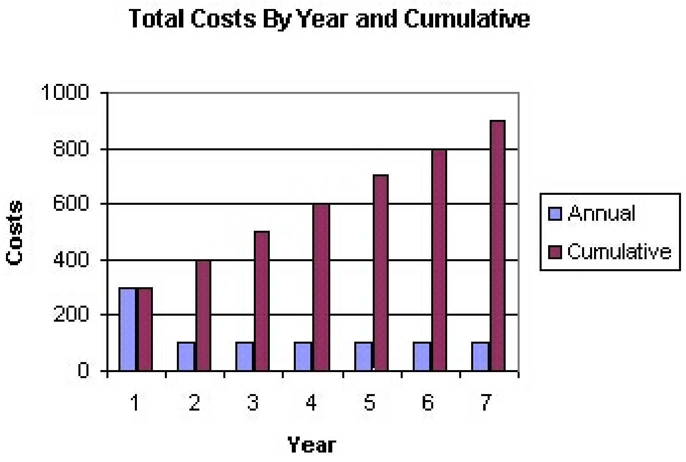
Installation, support, training, upgrades, and repairs usually dwarf the initial outlay.

When someone asks you how much did something "cost," you typically state a figure based on what was shown on the quote, invoice, or receipt. In the case of a sensor, this is often only the cost of the sensor and possibly an amount for shipping, taxes, and related transaction costs.

This cost accounting may make the boss and the finance department happy. It can also reduce effectiveness and profitability.

You may be thinking, "I'm only buying a simple sensor. What other costs could there be?"

Below is a list of other costs that you may incur in the purchasing, maintaining, installing, and use of your sensor. These costs, in total, can become much larger than the initial "invoice" purchase price (see Figure 7).



Installation - Does the sensor design require you to make a special mounting plate or is flexible mounting inherent in the product? How long does installation take? Can installation be performed by a lower-skilled employee or must a higher-skilled technician or engineer perform the task?

Cabling, Connectors, And Signal Conditioning - Does the sensor require the purchase of additional electrical cable, electrical connectors, signal conditioning, and related instrumentation?

Reliability - What is the stated lifetime of the product? Does it have an MTBF (mean time before failure) rating? Does the vendor have reliability statistics of the product being used in an environment similar to your own? Unscheduled downtime costs can be huge in factory automation, aviation, and capital-intensive applications.

Scheduled Down Time - Is calibration or scheduled maintenance required? How will this downtime affect your operations? Will alternate sensors need to be installed? Can this work be done during other maintenance periods?

Repairs - Is the product repairable or is it discarded at the end of its lifetime? Are there costs associated with its disposal? Can the repair be performed on site or must the item be returned to the manufacturer?

Calibrations - Can calibrations be performed on site or is factory return required? How often are calibrations required and what is the cost?

Usability - Is the signal from the product easy to work with or does it require specialized power supplies, amplifiers, and related equipment that must be procured, installed, learned, and configured?

Lead Time - Longer lead times require you to spend more time scheduling and may require you to stock sensors to avoid stock out situations.

On-Time Performance - Does the sensor get delivered on time? If you planned for receiving the item in 7 days but the shipment does not show up for 21 days, you will spend valuable time re-scheduling resources and nagging the vendor to get the product to you.

Environmental Rating - Unintended uses can often make environmental protection an important feature. A misplaced cup of coffee or an inadvertent blow from a steel-toed shoe can wreak havoc on your "office environment" sensor and increase your costs. If you plan to add environmental protection yourself, remember to add this cost to the solution's total cost.

Shipping - It may not seem like much to pay a flat small fee for shipping. But add that flat small fee over spare parts, factory calibrations, repairs, and replacements and the amount can become substantial.

If shipping is based on weight and volume, look at the products you are considering specifying. Are there any size or weight differences? Are there are tariff differences related to the products originating from different countries?

Stocking Requirements - Lead time, reliability, repairability, ontime shipping, and other factors influence the stocking (inventory) levels required for the sensor.

A rule of thumb is that annual inventory carrying costs are 25% with ranges from 18% to 75% (PDF file). Your carrying costs may be higher than 25% based on this analysis:

Cost of Money	6 to 12%
Taxes	2 to 6%
Insurance	1 to 3%
Warehouse Expenses	2 to 5%
Physical Handling	2 to 5%
Inventory Control	3 to 6%
Obsolescence	6 to 12%
Deterioration and Pilferage	3 to 6%
Total	25 to 55%

Source: Richardson, Helen: Transportation & Distribution, "Control Your Costs Then Cut Them," December 1995.

To reiterate, the above are annual carrying costs that will continue as long as you hold the products in your inventory.

Warranty - What is the length of warranty? What are the terms of the warranty? Are extended warranties available? What are the warranty restrictions?

Training - Are there extraordinary education or training requirements to use the sensor and related instrumentation? Is calibration straightforward or is a course required?

Documentation - Are adequate user manuals and application notes available? Do users need to spend valuable time learning and documenting the product?

Customer Service - Is customer service readily available? What are the hours of operation? How responsive is customer service to your inquiries regarding pricing, shipping information, and repairs? Is Web site pricing and ordering available?

Technical Support - Is technical support available 24/7/365? Are there fees associated with technical support? Is the information provided complete, accurate, and timely?

The selection of the proper sensor for a given application includes an evaluation of the costs of the sensor. Initial purchase costs can be less than 20% of the product's lifetime costs.

Only by considering the lifetime costs can you ensure you are specifying an optimum solution for the application.

Reducing Displacement Sensor Cost

How can we reduce the lifecycle cost of displacement sensors in UAV applications? The answer to the question depends on the specific UAV application in mind, but here are a ways the total cost of ownership can be lowered.

Reduce Redundancy In Hardware - Redundant sensors are needed in critical aircraft applications where a sensor failure could lead to catastrophic results. UAV lifetime and expendability requirements allow for lower reliability. As such, UAV displacement sensing applications should be reviewed to determine which applications require redundant sensors and which do not. Reduced hardware redundancy may well be offset by new advances in control software that allows for predictive failure reporting and fault tolerant control.

Easier Signal Conditioning - Many sensors on today's aircraft require expensive and heavy signal conditioning for amplifying, converting, or filtering signals. Selecting sensors that require modest or no signal conditioning will have the synergistic effect of reducing cost, size, and mass.

Reduced, Simpler Power Requirements - Most UAVs use a low-voltage DC onboard power supply. By selecting sensors that use this same power supply, power conversion is eliminated. In addition, by using sensors that use low levels of current, the overall aircraft power requirements can be reduced allowing for lower weight and longer flight durations.

Flexible Installation and Servicing - The cramped confines of a UAV interior can make installation and servicing of components difficult and costly. Using a displacement sensor that can be easily installed and serviced in these confines reduces labor hours and aircraft downtime.

Interfacing to Software and Other Systems - Using displacement sensors with simple electrical interfaces simplifies the task of interfacing with software and other systems. This simplification reduces software development time and reliability as well as development efforts for other systems.

Use of COTS or Modified COTS Components - Commercial off-the-shelf (COTS) components are sometimes down on by aerospace engineers based on the demanding requirements of high-performance aircraft. However, many UAVs will fly at less than 200 knots and at altitudes less than 10,000 feet. Therefore, it is possible the COTS components will meet many UAV requirements. This is particularly true in today's automotive sensors where automotive performance requirements can rival that of aerospace components.

Proprietary Design Benefits and Costs

A side note on reducing displacement sensor costs relates to the use of a proprietary or custom-designed sensor. The use of a custom-designed displacement sensor has a number of benefits including easier installation, simpler mechanical and electrical integration, lower operating costs, and potentially better performance. However, these advantages can be outweighed by the sometimes tremendous costs of a proprietary sensor such as long lead times, non-recurring engineering charges, component procurement costs, and monopolistic vendor behavior. These costs are large. As mentioned previously, stocking costs can range from 25% to 55% annually. If a proprietary design has a 16-week lead time with a 10-unit minimum order level, the annual carrying costs of a proprietary sensor can quickly outweigh its performance benefits.

Cost Versus Performance

Reducing the cost of a displacement sensor may lead to a situation where costs are reduced but performance requirements are not met. How do we determine what type of displacement sensors are suitable for the task? The answer: very carefully.

Before we look at displacement sensor technologies and selection, let's face an unfortunate fact: there are no perfect sensors. Each technology has advantages and disadvantages and tradeoffs are inherent in the sensor selection process.

As an application development manager for a displacement sensor supplier, I receive numerous queries on how to solve a broad range of position measurement challenges. These inquiries run the gamut from the common (aircraft flight control surface movement) to the exotic (Formula One racecar suspension travel) to the seemingly impossible (three-dimensional tracking of a golf ball in flight from a fixed position).

These position-measurement challenges usually share one common element. They can be solved using a variety of solutions, but it's not always easy to determine the best one.

There are possibly more options for measuring displacement than any other type of sensed variable. While there may be more suppliers for pressure transducers, the variety of displacement sensor types and technologies is unmatched.

Let's take a look at various displacement sensor selection parameters.

Displacement Sensing Parameters

On what performance basis should you select a displacement sensor? As a starting point, let's look at the laundry list of parameters shown in Figure 8. While this list is not all-inclusive, it helps you begin to decide what parameters are relevant to your application.

Figure 8

What are your requirements? This table helps you rank your most important parameters and value specifications. Select relevant parameters, prioritize them, and then choose the appropriate value for the parameters.

Parameter	Relevant?	Ranking	Choices
Contact	○ Yes ○ No	___	○ Contact ○ Noncontact
Motion Type	○ Yes ○ No	___	○ Linear ○ Rotary
Dimensions	○ Yes ○ No	___	○ One Dimensional ○ Multidimensional
Measurement Type	○ Yes ○ No	___	○ Absolute ○ Incremental ○ Threshold (Proximity)
Range	○ Yes ○ No	___	○ < 1" (25mm) ○ 1" - 40" (25 mm to 1000 mm) ○ > 40" (1000 mm) ○ < 360° ○ > 360°
Physical Size/Weight	○ Yes ○ No	___	☐ Size Restriction______ ☐ Weight Restriction______
Environmental Protection	○ Yes ○ No	___	☐ Humidity ☐ Vibration ☐ Moisture ☐ Corrosion ☐ Temperature
Installation/Mounting	○ Yes ○ No	___	☐ Removeable ☐ Installation ☐ Time Limit______
Accuracy	○ Yes ○ No	___	○ Linearity ○ Resolution ○ Repeatability ○ Hysteresis
Lifetime	○ Yes ○ No	___	○ Cycles______ ○ Hours of Continuous Operation______
Cost	○ Yes ○ No	___	○ < 50 USD / 50 EUR ○ 50 to 500 USD / 50 to 500 EUR ○ > 500 USD / 500 EUR
Delivery	○ Yes ○ No	___	○ less than 1 week ○ 1 - 4 weeks ○ greater than 4 weeks
Output	○ Yes ○ No	___	○ Voltage ○ Current ○ Digital ○ Visual ○ Sensor Bus
Frequency Response	○ Yes ○ No	___	○ less than 5 Hz ○ 5 - 50 Hz ○ greater than 50 Hz

Perhaps the first parameter to address in any application is whether the sensor can physically touch the object being monitored. If your application is sensitive to outside influences, a non-contact sensor may be the most appropriate. Otherwise, a contact sensor might offer advantages not found in a non-contact sensor.

At first thought, non-contact sensors may seem like the superior solution for all applications. However, the decision isn't that clear cut.

Non-contact products can emit potentially harmful laser- or ultrasonic-based signals. These products also rely on having a clear visual environment to operate in. Frequency response isn't always as high as with a contact sensor, but costs are often higher. Finally, operating-temperature ranges are typically not as broad.

Another parameter to consider early on is whether you need to measure linear, rotary, angular, 2D, or 3D movement. Note that using cable-actuated displacement sensors, cams, pulleys, levers, electronics, software, and other methods can enable a rotary sensor to measure linear motion and vice versa. Lack of space, cost, and ease of mounting are a few reasons for doing this.

Once you decide if you require a contact or non-contact solution and are measuring rotary or linear movement, selecting a sensor technology becomes much easier.

Next, determine if you're monitoring one-dimensional or multidimensional motion. If the motion is multidimensional, see if you need to measure in multiple dimensions or if the object is moving in multiple dimensions and you only have to measure one of them. Often, multidimensional motion is measured with multiple one-dimensional sensors.

Consider if you have size or weight constraints. Figure 9 gives a size comparison of selected displacement sensors with a 254-mm (10-inch) range.

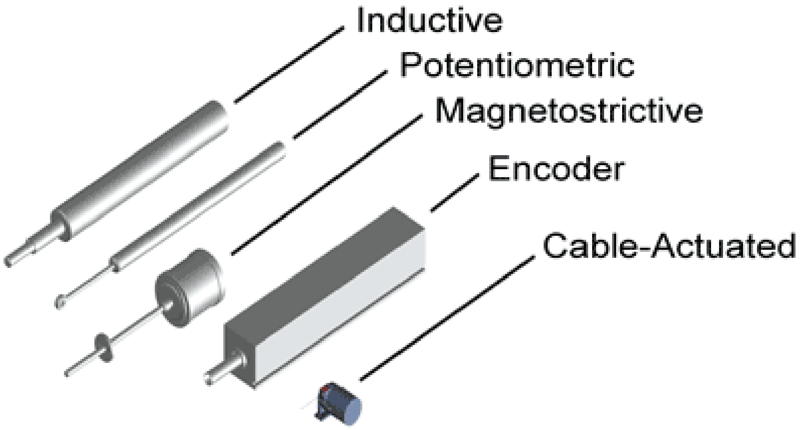


Figure 9 - Typical displacement sensor form factors for 254-mm (10-inch) range units shown to scale (fully retracted). From left to right: inductive, potentiometric, magnetostrictive, encoder, and cable-actuated.

Also, think about the type of signal you need to obtain. If you need a signal that specifies a unique position, be sure to specify a sensor with absolute output.

However, if all you need is relative position from a prior position or a simple on/off indicator, then incremental or threshold technology is more appropriate.

An important difference between incremental and absolute sensors is that incremental sensors typically need to be reinitialized after power-down by moving the monitored object to a home position at power-up. This limitation is unacceptable in some applications.

Threshold measurements are on/off in nature and usually involve limit switches or similar devices. As you might guess, absolute devices are usually more expensive than incremental or threshold devices.

Travel, also known as range, varies from microns to hundreds of feet. The range of many precision displacement sensors is limited to 10 inches (254 mm) or less.

The application's operating environment can have a large impact on your technology choice as well. You need to determine what operating and storage temperatures the device will be in and whether you need to meet commercial, industrial, or military environmental requirements.

Also consider whether excessive humidity, moisture, shock, vibration, or EMF will be encountered. Determine if your environment has other unique aspects, such as high or low pressure or the presence of hazardous or corrosive chemicals.

An often-overlooked parameter is the method and time required for sensor installation and mounting. For testing applications, this parameter may not be so important. However, OEM and large-volume applications often require simple installation and removal to reduce labor costs and enable easy maintenance.

Determine if the sensor can only be mounted with manufacturer-provided special mounting bases or if a variety of mounting techniques can be used. In addition to the common threaded-fastener approach, some other nonpermanent mounting techniques include suction cups, magnets, industrial adhesives, grooved fittings, and clamping.

In going through the previous parameters, you might have asked yourself, "Hey, what about accuracy?" While accuracy is certainly important and sometimes critical, it's often the last degree of freedom in the selection of a sensor.

As you may know from experience, accuracy is not a well-agreed-upon term. Typically, various components of accuracy - linearity, repeatability, resolution, and hysteresis - are quoted for vendor convenience or per user requirements.

With the availability of software calibration tools today, linearity isn't as important as it once was. For many applications repeatability is the most important component of accuracy.

Accuracy is typically specified in absolute units like mils or microns or in relative units such as percent of full-scale measurement. If you are comparing the accuracy of one device against another, ensure you are comparing apples to apples.

For example, see if the accuracies being quoted are at a single temperature or over a temperature range. If your application requires it, find out if temperature compensation is available.

It's a good idea to ask vendors what type of use their sensors see most often. Common uses include OEM, retrofit, military, space, commercial, and test and measurement. Hopefully, the sensor has seen previous use in your type of application.

Obviously, the sensor is going to be a part of a system. So, determine your preferred electrical input and output requirements. Common output choices include analog AC and DC voltage, resistive, current (4-20 mA), and digital.

Increasingly, outputs using bus protocols are being offered. Most displacement sensors require 50 V or less.

Finally, for fast-moving applications, determine the maximum velocity or acceleration that needs to be monitored and verify the sensor's frequency response. Ensure your data-acquisition or control system has an adequate sampling rate to record the resulting datastream.

Check Your Requirements

Now that you're aware of the key parameters, you need to determine which ones are relevant to your application and of these relevant parameters, which are most critical.

If you don't prioritize your requirements, it's going to be difficult to make a selection decision. You may come to the conclusion that there is no sensor that can meet your needs. This may be true, but it's more likely your requirements are too stringent and you need to make a tradeoff to arrive at the optimum selection.

For example, an engineer approached our company looking for a sensor with ±0.0001-inch (±0.025 mm) resolution over 30 inches (762 mm) and he wanted to keep the cost under $500. He was adamant that all three specifications be met. Our products didn't meet all his specifications and we were at a loss as to where we would refer him.

After more discussion, we found out the resolution requirement was only necessary over a limited portion of the total range and the cost goal, while important, did have some flexibility. Hence, in this situation, range was most important, followed by resolution, and then cost.

The moral of this story: focus on your top requirements. Make the best decision you can, given the specifications you need. And keep in mind, you can't have everything - unfortunately.

Next Steps

We looked at some parameters for selecting displacement sensors. But we didn't discuss what type of technology you should select for your displacement sensor.

The constant change in sensor technology and the difficulty in generalizing about a particular technology's capabilities and limitations mean there's no way I can cover this area in detail here.

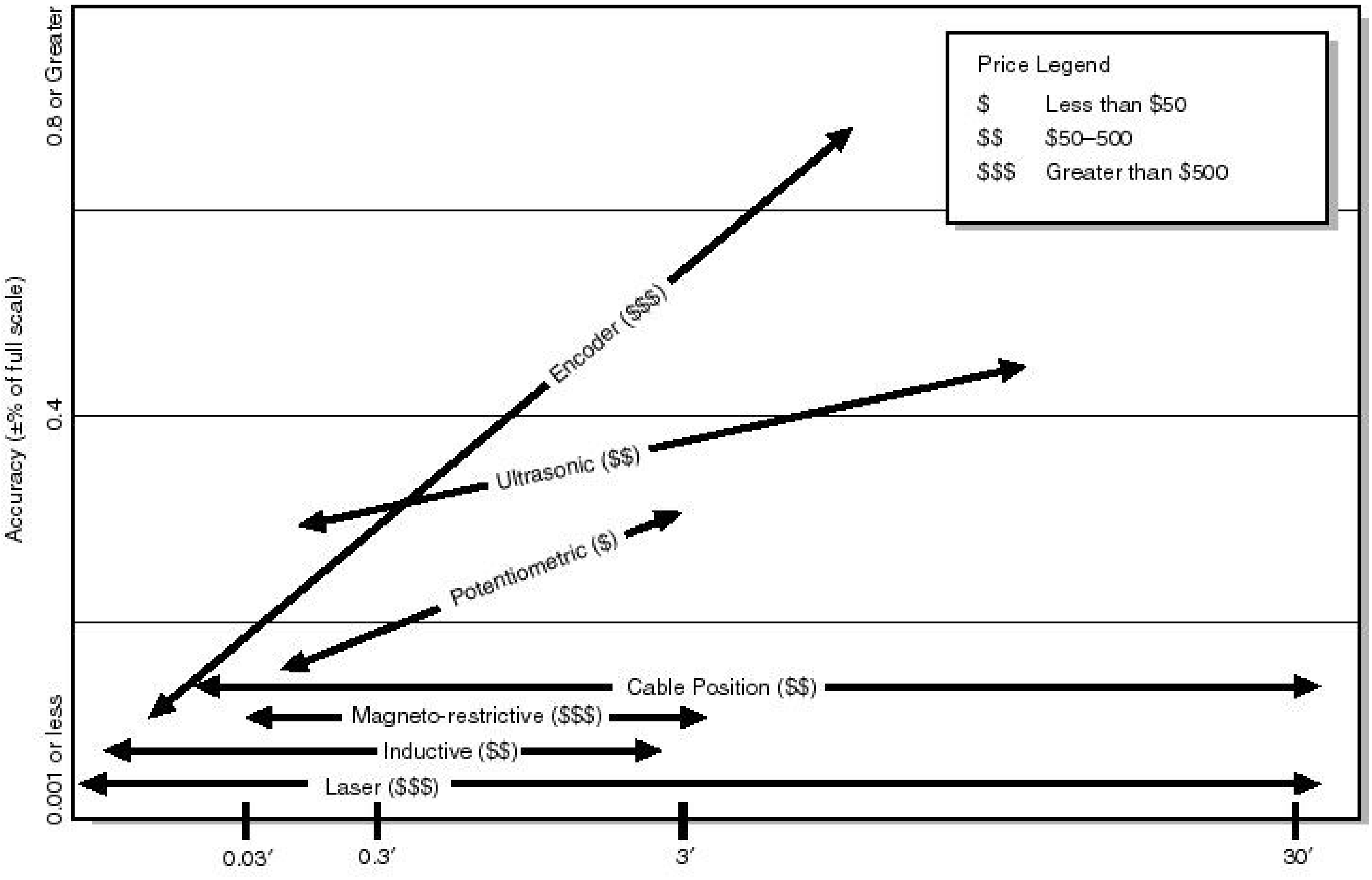
Additionally, choosing the technology should come after determining and prioritizing your requirements. Once your requirements are well-known, the choice of technology tends to be self-selecting.

For example, just knowing whether you require a contact or non-contact technology can cut your choices almost in half.

To get a feel for the capabilities of some of the more prevalent displacement sensing technologies useful in a UAV environment, Figure 10 maps out how these technologies compare against each other based on cost, accuracy, and maximum range. Not all technologies are shown. Appendix A gives a summary of five specific technologies.

Figure 10

It's true: you can't have it all. As with many specification decisions, tradeoffs must be made when you're selecting a position transducer. This graph shows the typical performance of some displacement sensors as compared by maximum range, best accuracy, and cost.



It may be difficult to clearly define the parameter values you require as well as which parameters are most important in your application. However, it can be even more difficult to obtain these parameters from vendors and then compare one vendor's statements against another's.

Ask your colleagues about their experiences and recommendations. Information on their failures and successes can be quite valuable.

Contact vendors and request references of similar applications. Ask these references why they selected the product they did and whether they're happy with their decision. Find out what other options they considered.

Finally, see if the vendor has product samples or evaluation units you can use for testing before purchase. If the vendor is hesitant to do this, offer to provide them with a test report summarizing your evaluation. This information may be valuable to them, and they may be more willing to assist you.

The Future

The sensor technologies discussed in this paper were initially developed 40 to 60 years ago. Tremendous improvements have been made over the years, particularly in the areas of reliability, lifetime, and size. Nevertheless, today's UAV design engineers are specifying the same sensor technologies as their grandfathers did. Some micro UAVs are smaller than some displacement sensors.

What does the future hold for displacement sensor technologies and cost reduction? Will a "wonder sensor" based on MEMS or non-contact technologies come upon the scene? Given the prevalence of incremental improvements in aircraft and technology, a wonder sensor seems unlikely. Yet, if displacement sensor capabilities begin to limit UAV design choices and UAV performance, increased resources will need to be applied if we are to avoid a situation where displacement sensors limitations drive UAV design.

Summary

UAV developments show innovation is alive and well in the aerospace industry. Hybrid designs incorporating rotary- and fixed-wing characteristics, micro UAVs, autonomous control, and a host of other features make UAVs one of the most exciting areas in engineering and technology today.

But, if UAVs are to gain broad acceptance, they must not only demonstrate they can be used safely but that they can also reduce costs compared to the MAV alternative. By doing an analysis of the unique requirements of UAVs and lifetime costs, displacement sensors can be selected that not only reduce the cost of the UAV but that may also improve UAV performance.

Additional Resources

- Selecting Position Transducers
- Sensor Cost of Ownership Calculator
- String Potentiometer and String Encoder Engineering Guide
- Sensor Total Cost of Ownership
- Application Note for Ground Vehicles/Transportation
- Application Note for Aircraft/Aerospace
- Application Note for Draw Wire Transducer Accuracy
- Position Transducer Data Sheets
- Position Measurement & Control Archives

Appendix A - Prevalent Displacement Sensing Technologies

Potentiometric devices work like variable resistors. Potentiometric devices have three integral connections: excitation voltage input, common return, and signal output connections. The input excitation is attached to the resistive side of the LRT. The input voltage flows through the resistive element until it contacts the wiper that couples the input voltage to the conductive side of the device, allowing the output voltage to exit the sensor. The common return is that it connects the negative side of the transducer to the return path of the voltage source, completing the circuit. The feedback voltage measured from the output signal changes proportionally to the position of the electric wiper, which is typically attached to the cylinder rod or piston. Potentiometric devices generally require low-voltage excitation.

Some advantages of potentiometric devices include low cost, small size, ease of integration and good accuracy. A disadvantage is that they are contacting devices, which may cause earlier wear than non-contacting devices.

Inductive transducers used for continuous feedback are typically linear variable differential transducers (LVDTs) for linear motion feedback, and rotary variable differential transducers (RVDTs) for rotary motion feedback. These are non-contacting devices that have high life expectancy, good accuracy, and high velocity ratings. They are medium in size and cost. The LVDT/RVDT works by moving an electromagnetic core linearly across primary and secondary windings of a transformer. When the core is centered, the feedback signal is zero. As the core is moved, the amplitude of the excitation voltage increases proportionally to the movement of the core. These devices require special signal conditioning boards to provide excitation and to interpret the feedback signal.

Magnetostrictive devices are accurate, non-contacting devices that offer high-life expectancy and high velocity. They are typically medium sized and high in cost.

Magnetostrictive devices function by sending electronic pulses down a wave guide until they encounter a magnetic field (typically supplied by a magnet that is attached to the device that is being positioned, such as an actuator piston), causing the pulse to distort. The position is calculated by timing the distorted return pulses. These devices require special signal conditioning boards to interpret the feedback signal pulses.

Encoders can be used for rotary or linear position feedback. They have digital feedback that is very linear and accurate. They are typically high in cost and are limited in some applications, because they are susceptible to shock, vibration, heat, and humidity. These encoders are optical devices that turn light into pulses by passing light through encoded grating on glass. Photodetectors change the light pulses into encoded voltage signals that can be interpreted to determine position. Encoders need special electronics to interpret the data.

Cable-actuated displacement sensors are hybrid devices that can incorporate potentiometric, inductive, synchro, or encoder technology. A significant portion of the sensor iis a stainless steel cable that is lightweight, - small, affordable, and flexible. This sensor allows for the technology of choice as sensing mechanism and, hence, adopts the electrical output characteristics of that sensing technology. See Figures 11, 12, and 13.

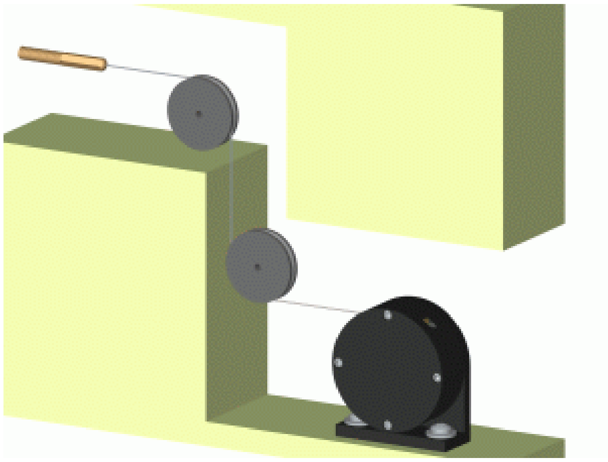


Figure 11 - Cable-actuated displacement sensor with pulley guides

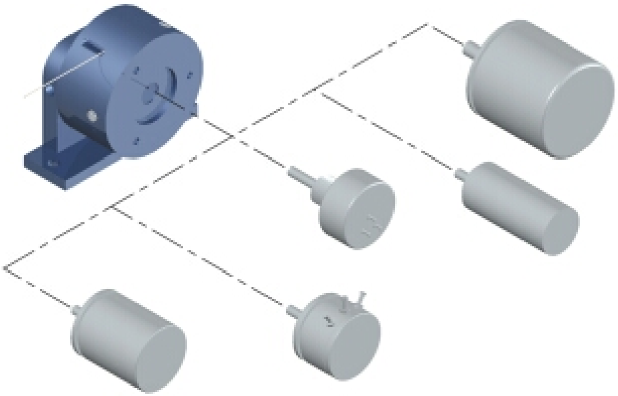


Figure 12 - Inductive, encoder, potentiometric, synchro, or resolver technologies may be incorporated into cable-actuated displacement sensors

Redundant Accumulator Position Flight Data Recorder Control Surface Fluid Level

Figure 13 - Examples of cable-actuated displacement sensor applications

Firstmark Controls • info@Firstmarkcontrols.com
An ISO9001:2000/AS9100B-Compliant Company
1176 Telecom Drive • Creedmoor, NC 27522 USA
Phone: 1-919-956-4203 • Fax: 919-682-3786 • Toll Free: 1-866-912-6232
Business hours: Mon-Fri, 8:00am to 5:00pm (Eastern time)

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