Wireless Sensing Opportunities for Aerospace Applications

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Abstract: Wireless sensors and sensor networks is an emerging technology area with many applications within the aerospace industry. Integrated vehicle health monitoring (IVHM) of aerospace vehicles is needed to ensure the safety of the crew and the vehicle, yet often high costs, weight, size and other constraints prevent the incorporation of instrumentation onto spacecraft. This paper presents a few of the areas such as IVHM, where new wireless sensing technology is needed on both existing vehicles as well as future spacecraft. From ground tests to inflatable structures to the International Space Station, many applications could receive benefits from small, low power, wireless sensors. This paper also highlights some of the challenges that need to overcome when implementing wireless sensor networks for aerospace vehicles.

Keywords: Wireless, Sensors, RFID, Modeling, Simulation, Surface Acoustic Wave (SAW)

1. Introduction

It has long been known that eliminating wiring and wiring harnesses will reduce the mass of vehicle health monitoring systems [1], and transitioning from wired to wireless systems is an excellent way to reduce the amount of wiring. Also, the use of Radio Frequency Identification (RFID) sensors for integrated vehicle health monitoring (IVHM) applications instead of wired network sensors will avoid costly redesign to route network cables and the costs of performing safety re-certification [2]. The Decadal Survey of Civil Aeronautics: Foundation for the Future [3], identified IVHM as the top NASA and national priority within the area of materials and structures. The survey also identified classes of IVHM systems that warrant attention over the next decade. “The second class includes locally self-powered, wireless microelectromechanical sensors of various types tiny enough that very large numbers of sensors become practical. Each sensor mote performs a point measurement, so many are used to effectively cover large areas". For these, and many other reasons, NASA is investigating the use of wireless and RFID technology for aerospace applications.

2. Potential Aerospace Applications for Wireless Sensing

2.1 Shuttle Applications

Spacecraft that re-enter the earth's atmosphere like the NASA space shuttle require sophisticated thermal protection systems (TPS). The integrity of the TPS is paramount for the safety of the crew. Recent Space Transportation System (STS) events have demonstrated the need for the addition of impact monitoring to the shuttle orbiter wing leading edge during takeoff; however, adding wiring to the space shuttle wing incurs an enormous cost. A wireless system will avoid the excessive costs and still detect impacts from foam and ice. An initial impact detector has been developed and flown, but there is a need to improve bandwidth, communication reliability, radiation tolerance, and battery life [4]. Acoustic emission data from impact hammer tests were performed on the Shuttle Endeavour's wing leading edge (Fig. 1) and wing spar in the range of 10 to 150 KHz to determine future upgrades to the existing wireless impact monitoring system [5].

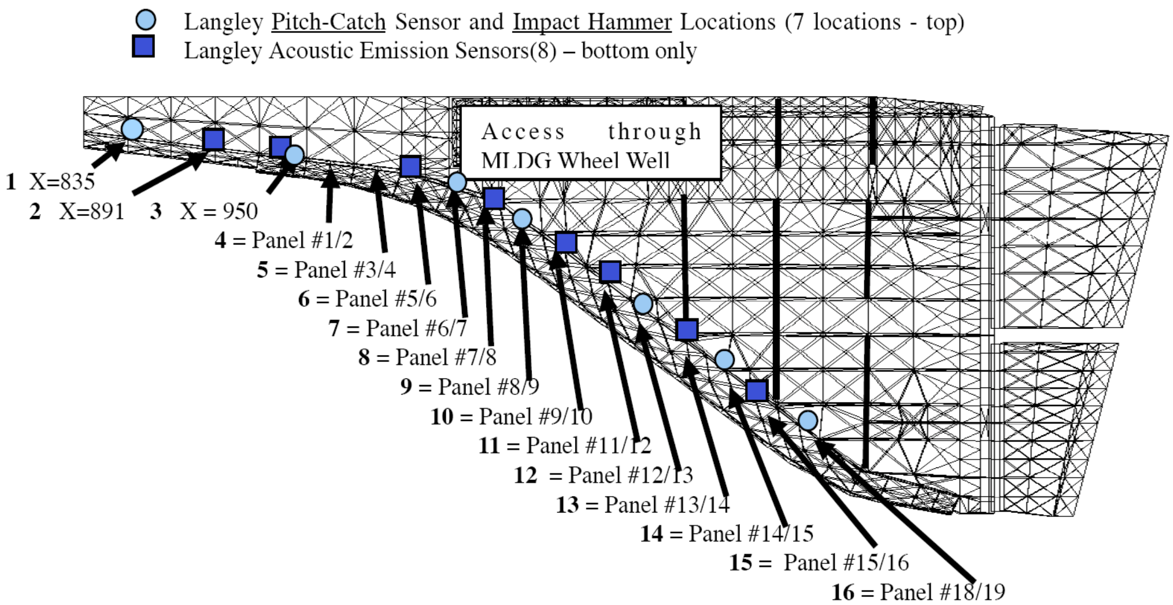


Fig. 1. Layout of transducer locations inside of the Shuttle Endeavour's wing.

A wireless system has also been designed to monitor the temperature of the space shuttle's TPS. The system utilizes RFID technology to determine whether a temperature threshold has been exceeded [6]. In addition to the aforementioned problems, the TPS could suffer from cracks, disbonds, and other structural defects that could be monitored by wireless systems [7].

2.2 International Space Station Applications

Long-duration space structures such as the International Space Station (ISS) are susceptible to micro-meteoroid and orbital debris damage. NASA has used the Small Business Innovation Research (SBIR) program to develop wireless solutions for ultrasonic detection of leaks due to damage in pressurized structures [4]. NASA is also investigating the tracking of inventory on the ISS. RFID technology has been proposed as one way to integrate logistics within a framework that will reduce the number of lost items [8].

2.3 Wearable Electronics

Body-centric or wearable electronics require light weight systems that are small, and flexible, and incorporate flexible antennas as well. Biotelemetry of astronauts, tracking information, and on-body inventories are but a few of the applications for wearable wireless systems that may be needed during long lunar missions or on Mars outposts [9]. It has been suggested that turn-around times for reusable launch vehicles could be reduced by going to a paperless system utilizing wearable computers and wireless communications [10]. Wearable electronics and wireless sensor networks are both emerging technologies that are likely to experience rapid growth in the future.

2.4 Inflatable Structures

Inflatable habitats are comprised of a rigid structural core and a pressure bladder that acts as the flexible shell. Figure 2 is the concept for the TransHab inflatable space structure. The rigid core contains primary structures, avionics, power and life support. The rigid core does not necessarily require wireless sensors; however, the flexible shell does, since wires do not always survive the folding process. Impact detection, leak detection, condensation on the inside surface of the bladder, humidity, pressure and strain, could be measured with wireless sensors. The shape of structure during folding and after deployment also needs monitoring [11].

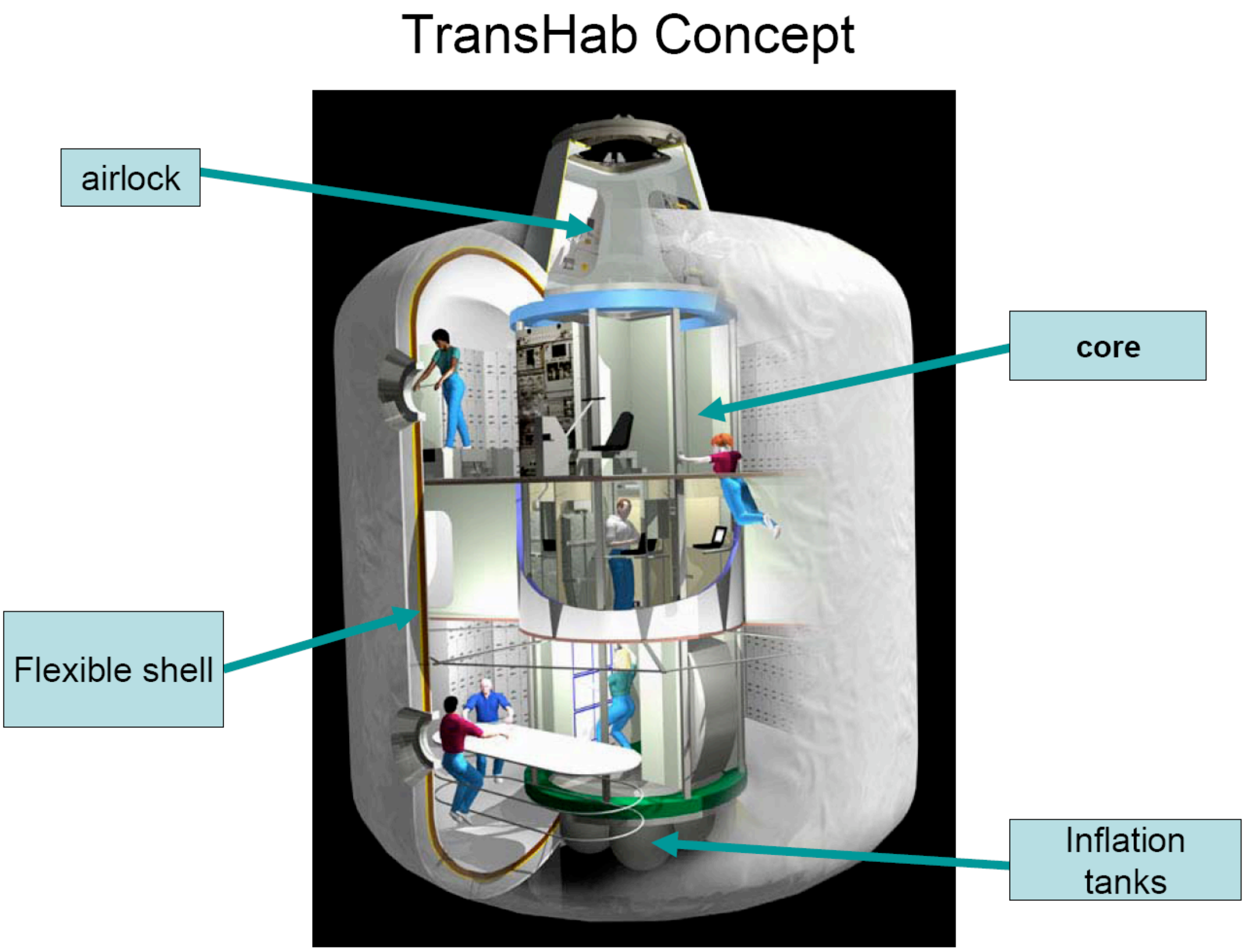


Fig. 2. Concept for the TransHab inflatable space structure.

Ideally, sensors for inflatable structures would be flexible instead of rigid, and therefore more compatible with being folded along with the bladder. Wireless sensors are required to reduce weight, and eliminate wires that must be flexed and folded. Inflatable structures will also need to have fault-tolerant avionics and wireless feed-throughs to pass communications and power to and from internal, external, and embedded sensors [12]. Since NASA is looking for light-weight habitats for use in space and on the moon, there will be numerous applications for wireless sensors that are flexible, passive, and light weight.

2.5 Aircraft Applications

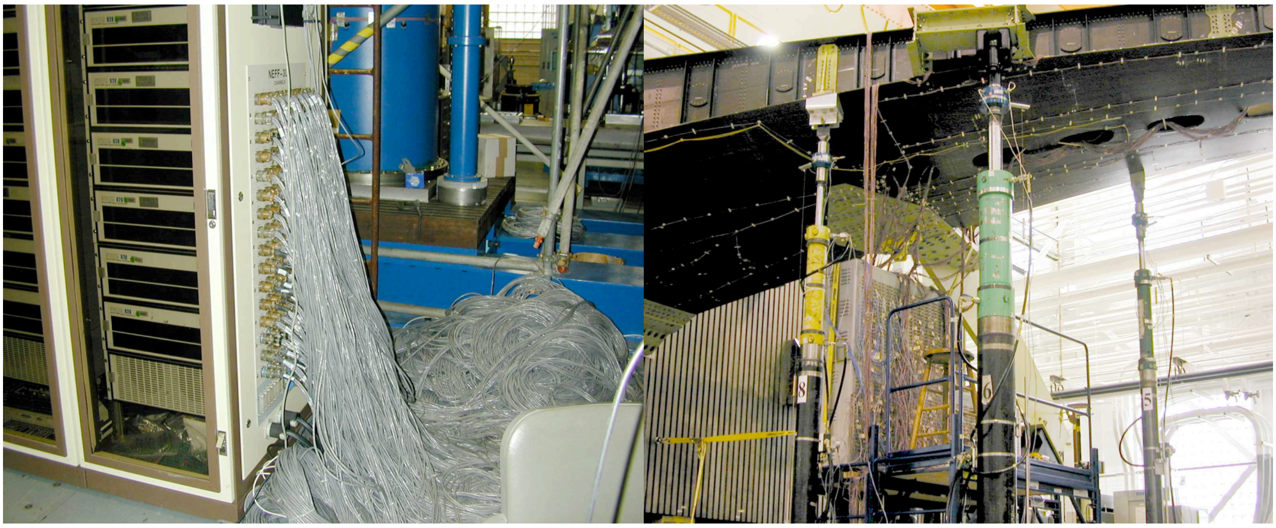
NASA envisions adding IVHM sensors to existing aircraft; however, the cost of retrofitting the vehicles with currently available technologies is too high. Installation of wiring for the sensors adds cost and weight to the aircraft. Also, wires are prone to damage such as nicks, breaks, degradation due to wear, excessive heating, and arcing. Wiring problems have led to major aircraft accidents and delays of space vehicle launches [13]. In contrast, wireless systems present a better option when retrofitting sensors onto existing aircraft. An adaptable wireless system has been developed and flown for health monitoring of aircraft landing gear [14]. The system was rigorously tested for flight qualification before it was flown on a NASA 757 aircraft. Other wireless sensor networks are being developed for monitoring the health of aircraft engines on commercial and military aircraft as well as on NASA aircraft [15, 16, 17].

NASA has been investigating the use of ultra-long duration solar powered aircraft (Fig. 3). The flights could last for weeks or months. This aircraft has need of shape sensors to detect the exact shape of the wing as it bends. Naturally the sensors must be extremely lightweight and low power. Wireless sensors would provide these characteristics and eliminate wiring weight as well.

Fig. 3. Helios, one of NASA's ultra-long duration solar aircraft.

2.6 Ground Testing Applications

NASA performs many experiments and tests that require the placement of large numbers of sensors on a test article. Currently, almost all of the sensors are wired to instrumentation. A common example is the stitched/resin film infused graphite-epoxy wing box, where 446 strain gauge sensors are connected to the test article using standard cabling techniques [18]. The time and cost to install and trouble shoot the connections of large numbers of cables can be prohibitive. Figure 4 shows a photograph of the cables required to connect the strain gages (Fig. 4a) to the stitched/resin film infused graphite-epoxy wing box test article (Fig. 4b). In the future, wireless sensors could significantly reduce the time and cost required for this testing.



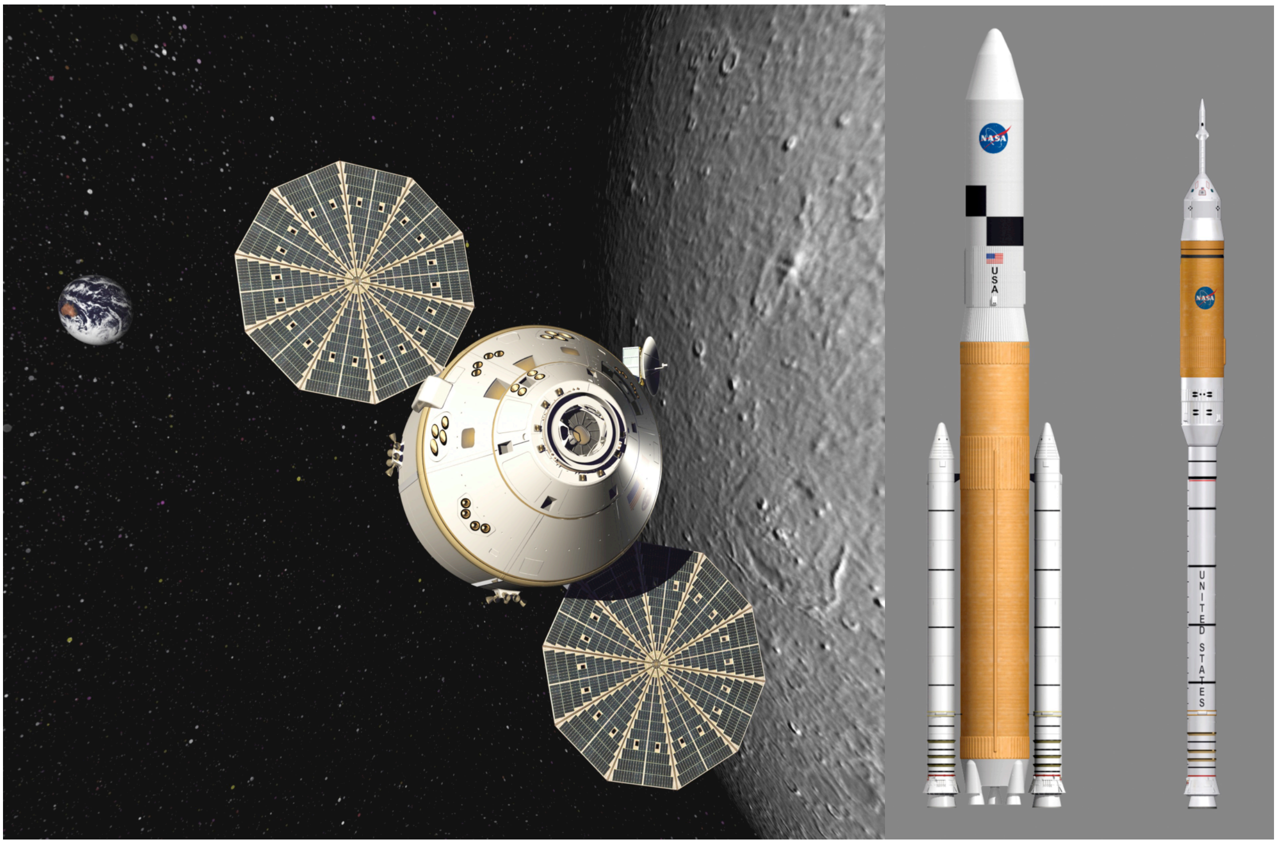
(a) (b)

Fig. 4. Photographs showing (a) the cabling required to connect 466 foil strain gages to (b) the stitched/resin film infused graphite-epoxy wing box, test article.

Other ground test applications exist for wireless sensors. At Kennedy Space Center (KSC), wireless sensor networks have been developed for monitoring cryogenic lines and for centering and aligning the external tank [19]. On-going work in the Transducers group at KSC integrates wireless communications with sensors and transducers. At Langley Research Center researchers have developed and tested a wireless fluid level system that works in harsh environments such as immersion in liquid nitrogen [20]. The device can work in variety of harsh environments while detecting the level of numerous "fluids" such as liquid nitrogen, transmission fluid, sugar and even ground corn.

2.7 Future Spacecraft

NASA has begun a new initiative to go back to the moon and to then to go to Mars. Although new technology will be required for these missions, the physics involved has not changed. For long duration flights, some issues become more critical, such as leak detection and IVHM. The new crew exploration vehicle (CEV), now called the Orion (Fig. 5a), and the new series of rockets NASA is developing, now called ARES (Fig. 5b), could benefit from wireless sensing. Needs have been identified for increasing the number of channels for sensing, decreasing installation time, and including more flexibility within the sensing systems, while simultaneously reducing the weight that must be launched into space [21]. These constraints are pushing the development of wireless technology for all future aerospace applications.



(a) (b)

Fig. 5. NASA's concept for the new space vehicles. (a) The Orion space capsule, and (b) the unmanned and manned Ares Rockets.

3. Challenges of Wireless Sensing for Aerospace Vehicles.

The main challenge for wireless sensor networks is power, sometimes batteries can be used, but many applications are in inaccessible locations and experience temperature extremes that preclude the use of batteries, and therefore require passive wireless sensing systems be developed. To alleviate the power issue in active wireless sensor networks, energy harvesting systems are being researched. However, current harvesting systems still depend on batteries for energy storage, because they cannot supply enough power for continuous operation.

In general, the cost, size, resources and energy required for wireless sensor networks must be addressed in the design phase [22]. The environment of aerospace vehicles is often very harsh with temperature extremes from cryogenic to very high temperatures, and pressure from vacuum to very high pressures. Shock and vibration levels during launch are often high enough to cause component failures. Another issue will be the certification of wireless sensor networks for flight. This includes the allocation of frequency spectrum for wireless sensing, along with the determination RF power levels, and FAA acceptance for aircraft use. Electromagnetic interference poses a problem for all wireless systems including sensor networks. Electronics must be designed to be tolerant if not hardened against higher levels of ionizing radiation for space applications [23]. Waste heat from electronics is difficult to dispose of in space when operating in vacuum conditions which eliminate all convection, leaving only conductive or thermal radiation methods for heat removal. Reducing the cost associated with retrofitting wireless sensors on aircraft and space craft is always a challenge. And last by not least, wireless sensor networks for aerospace application must have small volume, and mass due to the high costs associated with launching items to space.

4. Conclusions

The emerging technology of wireless sensing has many opportunities for Aerospace applications, and many issues that must be addressed. Both present and future spacecraft require wireless leak detection, and thermal protection system monitoring. IVHM is needed for aerospace vehicles and space structures; however, the cost of installation must be reduced before devices can be implemented. There are many challenges when implementing wireless sensor networks which must be investigated before wireless sensor networks will proliferate in aerospace applications. Power, volume, and mass must be reduced. Issues such as electromagnetic interference, ionizing radiation, thermal dissipation, vibration, shock, and harsh environments must be addressed. Despite the challenges, wireless technology offers benefits that cannot be ignored. This is an enabling technology that will allow the incorporation of large numbers of IVHM sensors onto aerospace vehicles.

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