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Incorporation of Nanosensors into Aerospace Vehicles

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Applications and Transformations

Abstract:

Traditional sensors are too big and heavy for installation in space vehicles, including the Space Shuttle Orbiter as well as future manned and unmanned vehicles currently in the early design phase. Advances in nanotechnology have led to the availability of smaller and more accurate sensors. Multiple and redundant nanosensors can be used to conduct more accurate and comprehensive measurements in a space vehicle. Early planning can lead to the relatively easy incorporation of miniature sensors sharing power and communication lines, thus reducing the requirement for large amount of electrical and/or optical cabling.

Introduction

It is expected that with the advances in nanotechnology, significant improvements will be achieved in the real-time monitoring of the health of space vehicles. Engineers will be able to place miniature sensors in locations where cost analysis had previously deemed unfeasible because of the large weight, volume, and power requirements of early generation monitoring devices. It is the responsibility of the developer of new sensors and devices to prove that the new technology can perform reliably in a relevant environment, especially when important decisions are based on the output of the nanosensors. The involvement of the developer does not end with the completion of the design phase. The technology provider has to remain involved with the user through installation, acceptance testing, and acclimation of the new technology.

Because of the complexity of spacecraft, and the need for extremely high reliability, multiple steps are required before a new family of sensors can be accepted for use in these vehicles. Proper planning and understanding of these steps is critical for the timely delivery and implementation of nanosensor-based systems. Costs associated with wiring and sensor installation are important parameters that are considered when performing cost-benefit analysis for a space vehicle. When multiple sensors are involved, some level of intelligence can be embedded at the sensor level to limit the flow of nonessential information and to reduce wiring and signal bandwidth requirements.

The application of nanosensors to the space programs is not limited to the space vehicles, but also to the ground support equipment. A multitude of ground-based sensors are utilized to sense gas leaks, pressure, temperature, vibration, etc. on the launch pads. The use of multiple identical sensors in a single substrate, or different types of sensors also in a single substrate, provides the capability to perform redundant and complementary measurements which can result in extended calibration cycles, thus reducing operating and maintenance costs.

ASRC Aerospace, a NASA prime contractor at the Kennedy Space Center in Florida, is working on the development of nanosensors for use at the launch pads and possibly on future space vehicles.

Requirements:

Traditional sensors are too big and heavy for deployment in space vehicles, including the Space Shuttle and the new ARES vehicles. The additional cost incurred by increased weight and power requirements, often is a deciding factor on weather certain sensors are used or not. There is a need in the market for small, low power, smart sensors with increased reliability and better performance than traditional sensors.

With the advances in nanotechnology and circuit miniaturization, multiple sensors can be integrated into a single substrate to combine different measurements in a single chip and at the same time, to add redundancy. The capability to perform redundant and complementary measurements can result in extended calibration cycles, thus reducing operating and maintenance costs by reducing the need for periodic recalibration of the sensors.

Costs associated with wiring, weight, power requirements, and sensor installation are important parameters that are considered when conducting the cost-benefit analysis of new measurements. When multiple sensors are involved, embedded intelligence at the sensor level can be used to limit the flow of non-essential information and to reduce wiring and signal bandwidth requirements. This is accomplished by pre-processing the signals at the sensor level and transmitting only the relevant information. The health of the sensors can be monitored and measurements validated by applying process knowledge rules embedded in the sensors. Simultaneously, the amount of data transferred can be minimized by emphasizing transfer of process information instead of the transfer of raw data.

Process:

For the successful commercialization and implementation of nanosensors for a space-based application, it is important to properly define certain parameters very early in the design process:

- **Sensor Specifications:** accuracy, sensitivity, selectivity, power consumption, response time, recovery time, bandwidth, dynamic range, stability, noise behavior, EMI susceptibility, etc.
- **Physical Characteristics:** Size, weight, volume, mechanical and electrical interfaces.
- **Environmental constraints determined by mission to be performed:** vibration, shock, corrosion, radiation, thermal management, etc.
- **Safety and Reliability:** as established by the end user, including the assessment of materials compatibility and intrinsically safe designs for hazardous environments.

The process involves developing a detailed set of requirements, including performance, physical, environmental, safety, reliability, and maintainability concerns. It is also important to establish and understand the qualification process that the sensor will be subject to in order to certify the product for use in a space environment. The developer of the sensor must define the documentation requirements for the qualification process so proper traceability can be maintained. Another important process is the establishment of a quality control process to monitor the design, fabrication, testing, and integration of the product into the vehicle or the ground support system.

The selection of materials for the sensors and the associated instrumentation is critical because certain materials can cause hazards in the space environment that are not apparent in the ground environment. Materials should be selected early, and their use approved by the user. The safety community should be involved early in the design process, even during the conceptual design phase to ensure that no unexpected constraints appear later in the design process. Certification and safety problems that are often found late in the design cycle can be avoided easily and less expensively if they are addressed early in the design process.

Design Stage:

Multiple sensors are being integrated in a single substrate in order to obtain redundant measurements and extend the calibration cycles. This involves processing signals and applying the proper algorithms to evaluate the performance of the individual sensors within a module. The embedded intelligence at the sensor level limits the flow of non-essential information between the sensor and the data processing equipment. The combination of different measurements in a single module results in smaller and lighter sensors, and simpler and less expensive installation.

There is always the need to establish a tradeoff between costs and benefits, thus the need to minimize installation and maintenance costs. The qualification process for flight in an expendable space vehicle is time consuming and expensive, and even more for a manned vehicle. Wiring and sensor installation can significantly add to the cost, especially when multiple sensors are involved.

Figure 1. The Space Shuttle Orbiter has over 200 miles of wiring.

As the sensors and associated circuits get smaller, means have to be provided to interface these very small sensors to wires and connectors. Wiring systems are being designed for self-reconfiguring to intelligently re-route signals "on the fly" as mission needs change, or to compensate for wiring failure— which is especially vital for unmanned craft or inaccessible vehicle areas.

Conductive polymers, metalized organic polymers, and carbon nanotubes that are tough, flexible, and light weight with conductivity approaching that of copper are in development to be used to replace traditional copper wire.

Gas Detectors:

Personnel living in a space environment as well as technicians and engineers preparing spacecraft for launch can potentially be exposed to small amounts of hazardous gases. It is important to be able to detect, identify, and quantify the presence of a gas, especially when its presence could lead to a fatal situation.

ASRC Aerospace and its partners: the University of Central Florida and the Center for Nanotechnology Research at NASA Ames Research Center are developing nano sensors for the detection of various types of gases. We are providing technical expertise in the transition of sensors developed at NASA Ames Research Center into units suitable for aerospace application and we are currently performing all the required environmental testing and materials compatibility analysis.

Summary:

The successful integration of micro and nanotechnology into space vehicles requires a coordinated effort between the developers and the users throughout the design, development, installation, and integration process. The selection of materials for sensors and associated instrumentation should be done jointly between designers and users since certain materials can cause hazards in the space environment that are not apparent in the ground environment.

ASRC Aerospace is continuing with the development of micro and nano sensors, and instrumentation for space applications. The design of these devices is being conducted taking into consideration possible applications not only in the Space Shuttle Orbiter, but more importantly in the next generation vehicles scheduled to replace the Orbiter starting in the year 2010.

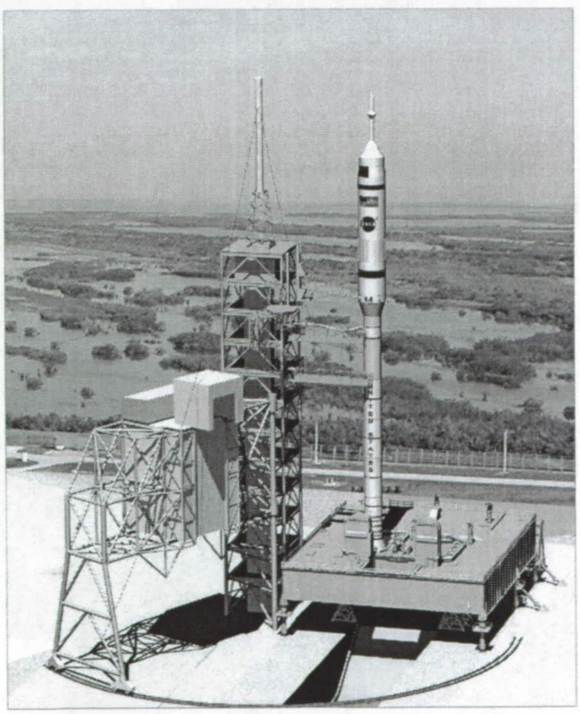

Figure 2. Ares I vehicle

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Space Shuttle

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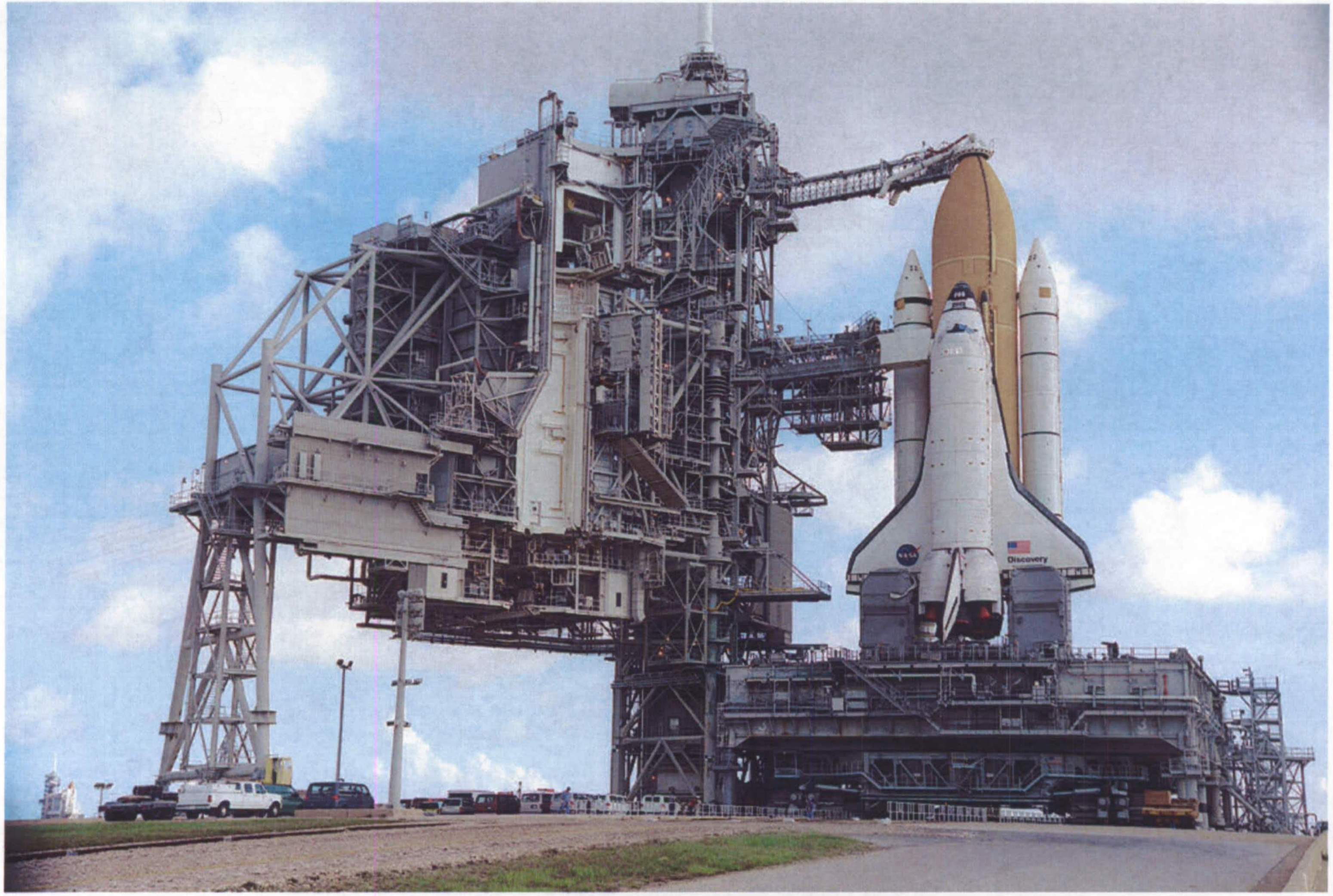

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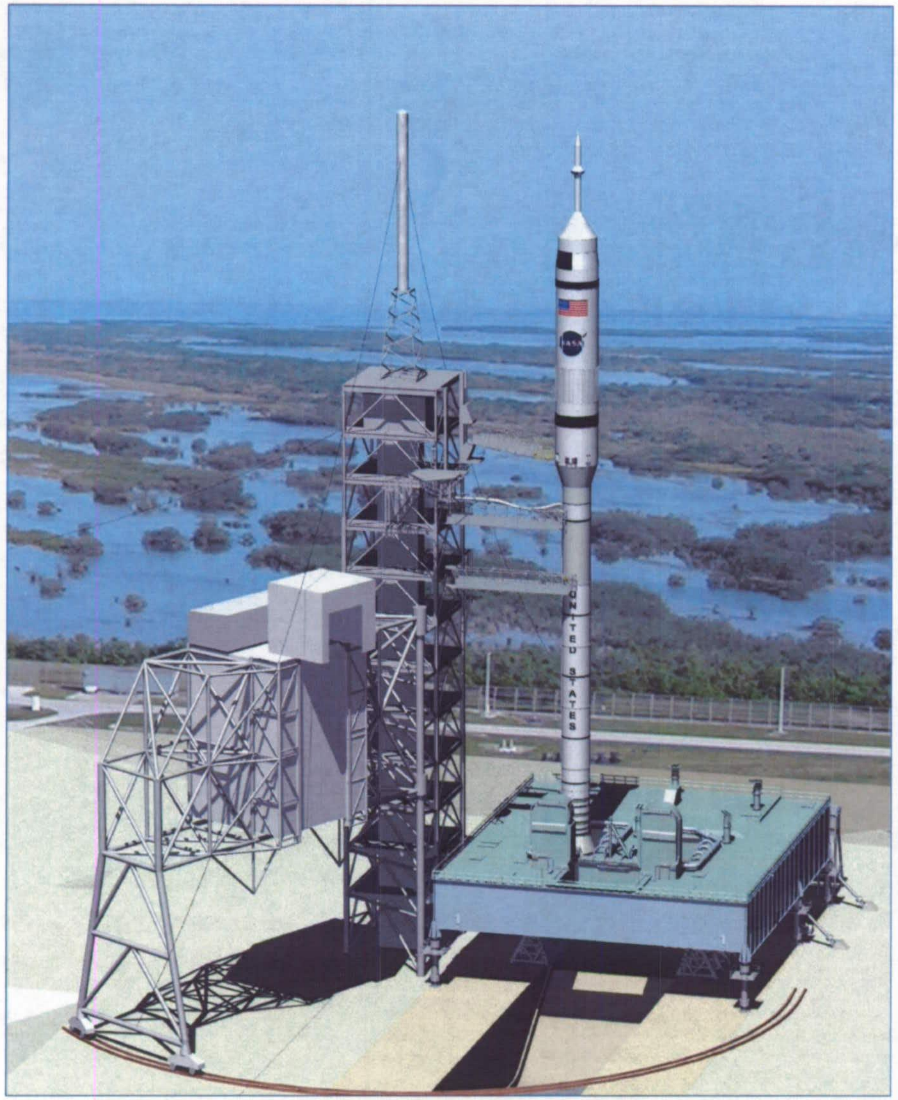

Introduction

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- It is expected that with the advances in nanotechnology, significant improvements can be achieved in the monitoring of space vehicles.
- Engineers will be able to place sensors in locations where cost analysis had previously deemed unfeasible.
- Although there are many steps associated with incorporating new systems into a space vehicle, proper planning and understanding of these steps is critical for the timely delivery and implementation of the new technology.

Requirements

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- Some sensors are too big and heavy for deployment in space vehicles, including the Space Shuttle and the new ARES vehicles.
- There is a need for small, low power, smart sensors with increased reliability and better performance.
- Multiple sensors can be integrated into a single substrate to combine different measurements in a single chip and add redundancy.
- The capability to perform redundant and complementary measurements can result in extended calibration cycles, thus reducing operating and maintenance costs.

Requirements

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- Costs associated with wiring, weight, power requirements, and sensor installation are important parameters that are considered when conducting cost-benefit analysis.
- When multiple sensors are involved, embedded intelligence at the sensor level can be used to limit the flow of non-essential information and to reduce wiring and signal bandwidth requirements.
- The health of sensors can be monitored and measurements validated by applying process knowledge rules embedded in the sensors.
- Data transfer can be minimized by emphasizing transfer of process information versus transfer of raw data.

Requirements

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- **Sensor Specifications:** accuracy, sensitivity, selectivity, power consumption, response time, recovery time, bandwidth, dynamic range, stability, noise behavior, EMI susceptibility, etc.
- **Physical Characteristics:** Size, weight, volume, mechanical and electrical interfaces.
- **Environmental constraints determined by mission to be performed:** vibration, shock, corrosion, radiation, thermal management, etc.
- **Safety and Reliability:** as established by the end user, including the assessment of materials compatibility and intrinsically safe designs for hazardous environments.

Process

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- Develop a detailed set of requirements: performance, physical, environmental, safety, reliability, and maintainability.
- Establish the qualification process to certify the product.
- Define the documentation requirements for the qualification process.
- Establish a quality control process to monitor the design, fabrication, testing, and integration of the product into the vehicle or the ground support system.

Process

ASRC AEROSPACE CORPORATION

- The selection of materials for sensors and associated instrumentation is critical because certain materials can cause hazards in the space environment that are not apparent in the ground environment.
- Materials should be selected early, and their use approved by the user.
- The safety community should be involved early in the design process, even during the conceptual design phase.
- Certification and safety problems that are often found late in the design cycle can be avoided easily and less expensively if they are addressed early in the process.

Multi-sensor Arrays

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- Multiple sensors (not necessarily identical) are being integrated in a single substrate.
- Redundant measurements result in extended calibration cycles.
- Embedded intelligence at the sensor level limits the flow of non-essential information between the sensor and the data processing equipment.
- Combining different measurements in a single module results in smaller and lighter sensors, and simpler installation.

Costs

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- It is important to establish a tradeoff between costs and benefits.
- Qualification for flight is time consuming and expensive, even more for a manned vehicle.
- Wiring and sensor installation adds to the cost, especially when multiple sensors are involved.

Integration of Micro/Nano sensors

ASRC AEROSPACE CORPORATION

- Means have to be provided to interface very small sensors to wires and connectors.
- Wiring systems are being designed for self-reconfiguring to intelligently re-route signals "on the fly" as mission needs change, or to compensate for wiring failure— which is especially vital for unmanned craft or inaccessible vehicle areas.
- Conductive polymers, metalized organic polymers, and carbon nanotubes that are tough, flexible, and light weight with conductivity approaching that of copper are in development to be used to replace traditional copper wire.

Sensor Efforts: Gas Detectors

ASRC AEROSPACE CORPORATION

- Personnel living in a space environment as well as technicians and engineers preparing spacecraft for launch can potentially be exposed to small amounts of hazardous gases.
- It is important to be able to detect, identify, and quantify the presence of a gas, especially when its presence could lead to a fatal situation.
- ASRC and its partners: the University of Central Florida and the Center for Nanotechnology Research at NASA Ames Research Center are developing nano sensors for the detection of various types of gases.
- We are providing technical expertise in the transition of sensors developed at NASA Ames Research Center into units suitable for aerospace application.
- We are currently performing all the required environmental testing and materials compatibility analysis.

Current Efforts

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- Conducting experiments on nano materials.
- Developing, testing and evaluating nano sensors and other nanotechnology based devices.
- Investigating new technologies leading to more sensitive and more accurate sensors.
- Identifying applications and requirements for nano sensors for ground support and space applications.

Summary

ASRC AEROSPACE CORPORATION

- The successful integration of micro and nanotechnology into space vehicles requires a coordinated effort throughout the design, development, installation, and integration process.
- The selection of materials for sensors and associated instrumentation is critical, as certain materials can cause hazards in the space environment that are not apparent in the ground environment.

Summary (cont.)

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- Scientists and engineers strive to build the most scientifically perfect system possible regardless of the time it takes.
- Flow managers like to ensure that all experiments and systems are integrated in the timeframe necessary to ensure that the overall mission launches on time.
- A compromise has to be reached where the requirements are met within an acceptable timeframe.

Summary (cont.)

ASRC AEROSPACE CORPORATION

- ASRC Aerospace is continuing with the development of micro and nano sensors, and instrumentation for space applications.
- The design of these devices is being conducted taking into consideration possible applications not only in the Space Shuttle Orbiter, but more importantly in the next generation vehicle scheduled to replace the Orbiter by the year 2010.

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14. ABSTRACT
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