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# Milestone report on aerospace control

IFAC Technical Committee on Aerospace*

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## 1. Current status

### 1.1. Brief history of the field

Powered aeronautical applications began with the successful flight of the Wright Brothers aircraft in 1903, and different airborne means of automation have continuously improved. Serious aerospace applications of automatic control began with the successful V-2 guided rockets developed in Germany under the leadership of Wernher von Braun.

After World War II the famous "von Braun Team" was brought to the USA to continue their rocket work together with Americans. Also, in 1946 a large-scale rocket program was started in the USSR under the leadership of Sergey Korolyov. The original developments both in the US and in the USSR were concentrated toward the creation of ballistic missiles for delivering munitions. But in 1957 the successful launch of SPUTNIK by the USSR added a new dimension to aerospace technology, i.e. putting objects in space and on orbit. In the 1960s, both the USSR and the US established manned space programs. In 1961 Yury Gagarin accomplished the first orbital flight in the Vostok spacecraft, launched by an R-7 rocket. In the US the Saturn V was developed as part of the Apollo program, through which astronauts went to the moon in 1969, and Neil Armstrong planted his foot on the surface of another celestial body.

Starting in the 1960s, both the US and the USSR launched numerous space probes to gather information on other planets and masses in the solar system. Unmanned automated spacecraft were landed on the Moon, Mars, Venus, and recently on an asteroid. Also, manned space stations have been launched into near-Earth orbits since the 1970s; SKYLAB was the first one. The long-lived space station MIR was launched in 1986 and carefully removed from orbit in 1999. At present the International Space Station is being developed.

In the 1970s the US developed the Space Shuttle. Later the USSR realized the fully automated horizontal landing of the space plane BURAN. The US launched the Hubble Space Telescope so scientists could peer deeper into the universe.

Since the 1960s thousands of satellites have been placed onto orbits around the Earth for the purposes of communications, remote sensing, navigation, reconnaissance, intelligence, etc. In recent decades not only the US and Russia have launched satellites, but also Western Europeans jointly through the ESA, Japan, China, and other countries have developed and launched satellites of different masses and purposes and have evolved new automatic control systems.

The automatic control systems of planes, helicopters and many other aeronautical machines have been continuously improved. Air defense and antimissile defense systems have integrated the best from other aerospace technologies to develop complex and accurate guidance and control systems. The development of high-speed, compact onboard computers has revolutionized all aerospace control systems and has made possible the implementation of sophisticated, adaptive control laws for guidance, attitude, and pointing control.

All branches of aerospace control have the deep mutual interconnection and were developed in the frame of a single scientific field.

### 1.2. Key problems being addressed within the field; typical applications

Aerospace control systems are required to be high performance, with little room for error. Most control systems must be designed to suppress vibrations and reject disturbances, while maintaining proper attitude control. For example, the International Space Station has high precision pointing systems that are useless unless they dampen out the excitation of structural vibrations and reject or suppress externals disturbances such as spacecraft docking, the movement of astronauts

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or the operation machinery. The control systems for aircraft and missiles must also be designed to dampen structural modes and to reject disturbances, e.g., wind, while following speed and altitude profiles.

Mathematical techniques and computational aids for designing high performance control systems are plentiful. A major problem, that control engineers of aerospace systems face, is obtaining an accurate mathematical model. An adequate model cannot usually be obtained until the system is built and tested. In some instances testing can only be done after the system becomes operational.

In regard to space and aircraft, some of the most pressing problems are associated with resources: monetary cost, facilities, and capable humans (including engineers). These three items are related. As aircraft get bigger in an attempt to maximize the efficient utilization of available air space, the need for adequate manufacturing and handling facilities arises. The need for modernized testing facilities also arises, as well as the need for improved communications facilities (including ground-to-air and Earth-to-space).

No high-performance control system will meet performance specifications without high-quality sensors and actuators. Most aerospace control systems are attitude and/or pointing systems. For example to design an autopilot for automatic landing of an aircraft there must be accurate measurements of aircraft altitude, speed, and lateral location and there must be control surfaces for changing flight direction and altitude.

Another problem involves the correct usage of computers. Too often young (and sometimes even seasoned and older) engineers embark on unthoughtful usage of modern computer software without questioning the results produced. Our educational systems must be careful to make sure that the graduates clearly know and understand the fundamentals and basics, rather than know how to get numbers from a computer code whose inner workings they know little or nothing about. They must also realize that computer codes are based on theoretical assumptions and, as a consequence, have inherent limits. They must make sure that the problem for which they are applying the computer software actually fits within these inherent limits.

### 1.3. General approaches/solutions being developed

There are continued developments of global navigation satellite systems (such as GPS and Glonass) to aid in precise navigation and control of aerospace vehicles. Work continues on the development of sensors and actuators that are more reliable and accurate, e.g., semiconductor accelerometers, micro-gyros, deformable mirrors, and piezo-electric devices.

### 1.4. Recent major accomplishments

In the past few years, significant developments have been made in the development of components for aerospace systems. Some of these are as follows:

- Development of micro-mechanical gyros and inertial gauges and algorithms for their effective integration with GPS receivers and other navigational sensors.
- Development of control systems for precise injection of satellites into near-Earth orbits for global navigation, communication, monitoring and other space-based systems.
- Creation of precise guidance systems for missiles with limited range.
- Development of attitude control systems of flexible structures with great accuracy and reliability.
- Development of thoroughly reliable relative motion control systems for approach and docking of spacecraft and space stations.

## 2. Forecasts: future trends & forecasts

### 2.1. Needs, challenges, opportunities

During the past 10 years significant advances have been made in aerospace systems and hardware. The future promises to bring dramatic advances. Some of these are:

- Fully automated airplane landing, irrespective of weather, to provide on-time arrivals of all flights.
- Creation of multipurpose flying vehicles with an increase in functional capability by improving on-board automatic control systems.
- Increase of GPS noise-proof factor.
- Increase of sea surface use for different aerospace vehicles for take-offs and landings, irrespective of sea state, in order to unclog the aerodromes and cosmodromes.
- Creation of effective antimissile defense guidance systems for preventing danger from terrorists.
- Providing the extra long-term functioning of unmanned space probes for investigating deep space, far-out planets and stars.
- Creation of perfect control systems for providing Wing-in-Ground machine safety and efficiency.
- Creation of special control units and systems for miniature flying machines on the base of mechatronics principles.
- Decreasing the space launch cost by controlled landings of potentially re-useable stages.
- Development of the next generation Supersonic Transport aircraft. The vehicle configurations will be large ($\sim$300 passengers), with very slender fuselages and will be highly unstable aerodynamically. To deliver the handling and ride qualities necessary for

such a vehicle, active structural mode control will be necessary. From an aircraft dynamics-and-control perspective, this level of instability coupled with the structural flexibility is unprecedented. There has been no prior experience in certifying a highly unstable commercial aircraft, let alone one with bending frequencies that will be extremely low.

### 2.2. Anticipated new developments

Classical control design techniques are cumbersome for designing controllers of complicated plants that are multi-input–multi-output. Modern control is weak in designing controllers for a plant with many flexible modes in the control bandwidth and with uncertainties (e.g. modal gains and/or frequencies) in the plant model. Also, modern control is weak in using test data to fine-tune a controller. There will be continued efforts to develop algorithms and computational aids for fine-tuning control systems using data from testing and for performing designs with model uncertainties.

At present, various types of algebraic design approaches are being proposed to overcome the shortcomings of classical and modern control techniques. For example, one such algebraic design approach that is being developed in Japan is to use polynomial matrices instead of state space equations or transfer functions.

### 2.3. Likely new applications

In the future, it is likely that many of the highly technical developments and ideas that have in the past been mainly used in aerospace will see application in other disciplines, and many of the past developments will have to be updated to be used in the development of new aerospace systems. Some of these are

- GPS guidance of tractors to plow fields without the need for a driver.
- Commercial planes without human pilots.
- Armies made up of robots.
- Air forces and space forces without human pilots.
- Space and ground based lasers for missile defense.
- Development of super jumbo jets (600 plus passengers).
- Development of very large supersonic planes.
- Manned missions to Mars.
- Unmanned marine vehicles.
- Development of new or improved propulsion systems, e.g., chemical, ion, nuclear, etc.
- Vibration and disturbance control systems for automobiles, trucks, and trains.
- Automated collision warning and avoidance systems for automobiles, trucks, and trains.