# Introduction

## Purpose and Scope

Spacecraft navigation data is exchanged during cross support of space missions. The purpose of this document is to establish a common understanding for the exchange of spacecraft navigation data. For purposes of this document, orientation and maneuver information are included as part of the spacecraft navigation process. This document presents the general definitions and terms of spacecraft navigation and flight dynamics, as well as the technical definitions and conventions used widely to describe the properties, measurements, and ancillary information of spacecraft dynamics required for navigation. The Navigation Data Messages Overview presents an overview of the CCSDS standard navigation messages.

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## Applicability

This document applies to navigation and attitude data exchanged in the following cases:

– flight-to-ground;

– ground-to-flight;

– ground-to-ground;

– flight-to-flight.

This document serves as a guideline for the development of compatible, inter-Agency standards for the exchange of spacecraft navigation and attitude data.

## STRUCTURE OF THIS DOCUMENT

1. Section 2 provides a brief overview of spacecraft navigation.
2. Section 3 provides foundational information regarding the components of a message exchange architecture (definitions, paradigms, etc.).
3. Section 4 provides details about coordinate frames, time systems, astrodynamic constants, environmental models, and other ancillary concepts important in spacecraft navigation.
4. Section 5 discusses properties of the entities that participate in a navigation data exchange.
5. Section 6 discusses the types of measurements that may be made during a navigation session.
6. Annexes A and B constitute a Glossary of Terms and a listing of Acronyms, respectively.

# scope of navigation

## general

This section briefly describes the spacecraft navigation process, and defines terms relevant to this process.

## NAVIGATION

### DEFINITION

The word ‘navigate’ is derived from the Latin words *navis*, meaning ship, and *agere*, meaning to move or direct. The common definition of navigation establishes that it is the science of getting a craft or person from one place to another. In this document, **navigation** means the determination and prediction of spacecraft orbits and attitude, which are specified by its translational and rotational motion, respectively.

### definitions of spacecraft navigation terms

In order to establish a solid standard for the exchange of spacecraft navigation data among agencies, it is important to clearly define terms relevant to this process. These terms are as follows:

**Navigation** is the process used to find the present and imminent future position, orbit and orientation of a spacecraft using a series of measurements.

**Orbit** is the translational motion of a spacecraft around a large central body, resulting from the gravitational forces of the larger mass acting on the spacecraft. The orbit of a spacecraft is the trajectory that does not, in the absence of perturbations, intersect with the central body. This trajectory is the path of a small mass, or spacecraft, orbiting the large central body through space. The orbit can be represented bas position and velocity in a state vector, or as orbital elements. There are other types of orbits that are affected by the gravitational pull of two larger masses, e.g. the Moon and Earth, such that the spacecraft with an appropriate velocity will remain in the same position relative to the two larger bodies. The orbits are called Lagrange or libration point orbits.

**Attitude** is the orientation and/or pointing of a spacecraft and it is defined by its rotation relative to a defined reference coordinate system. The preferred attitude representation depends on the attitude stabilization of the spacecraft. For instance, the attitude of a spin-stabilized spacecraft can best be represented by the attitude of a single axis either as a three-component unit vector or as a point on the unit celestial sphere. This representation sometimes includes the phase of rotation about that axis. For three-axis stabilized spacecraft, the attitude can best be represented by a coordinate transformation from reference axes in inertial space to the spacecraft body frame.

**Orbital dynamics** studies the changes in the position of all orbiting bodies, whereas **attitude dynamics** deals with changes in the orientation and pointing of the spacecraft. **Flight dynamics** is a term used to cover both orbital and attitude dynamics. It refers to the study of translational and rotational motion and control of a flying object, whether it is an aircraft of spacecraft. Within the aerospace industry, the flight dynamics term could be used for mission design and analysis as well as the support required for determining, controlling, and maintaining the orbit and attitude of a spacecraft.

**Orbit determination** and **attitude determination** are processes within navigation to find the present and past positions and orientation of a spacecraft using a series of measurements. These two navigation processes fit a set of measurements to a physical model in some optimal way to obtain the best orbit and attitude solutions. Although they are related, these processes affect each other only weakly so they can generally be performed separately. For example, a nominal attitude can generally be used in drag models that affect orbit determination, and predetermined ephemeris can generally be used in attitude determination. The results of these two processes are used to predict the immediate future position and orientation of the spacecraft.

**Guidance** is the process of defining a path to move a spacecraft from one point to another or from one orientation to another.

**Control** is the process to maintain a spacecraft within the prescribed path and attitude.

The guidance, navigation, and control terms above are commonly abbreviated to form **GN&C**. The **GN&C** term is used as a system of subsystem forming part of a spacecraft or aircraft. The GN&C system includes all the hardware (sensors and actuators) and software necessary for both onboard orbit and attitude determination and control.

The **Attitude Control System (ACS)** is part of GN&C and consist specifically of hardware and software for onboard attitude estimation and pointing control. The **Attitude Determination and Control System (ADCS)** term is sometimes used instead of ACS. The propulsion system is an essential element of GN &C and a complement for ACS within a spacecraft for attitude and/or orbit thruster control.

The responsibilities for guidance and control are outside of the scope of this Report.

### SPACECRAFT NAVIGATION PROCESS

In its simplest form, navigation is the determination of the position and/or orientation of an object. The position problem is generally called orbit determination and the orientation problem is called attitude determination. Orbit and attitude determination, although related, affect each other only weakly, so they can generally be performed separately. For example, a nominal attitude can generally be used in drag models that affect orbit determination, and a predetermined ephemeris can generally be used in attitude determination.

The navigation process fits a set of measurements to a physical model in some optimal way. The physical model represents the relationship between the measurements and the desired solution (position, velocity, etc.). Often additional model parameters that affect the solution are also solved for to improve the navigation solution. Examples of such parameters are drag coefficients or gyro biases. The set of all parameters that is solved for is called the state of the system.

For example, if one knows the position of a spacecraft, it is easy to compute the distance from the spacecraft to known points. The reverse process, computing the position of the spacecraft from a distance measurement, does not give a unique solution. To obtain a unique solution, distances from several known points at one time are needed. Alternatively, distances from known points at different times or different types of data (e.g., velocity measurements) can be used. In order to use the time-dependent differences, a model of the change of position of the spacecraft with time must be generated from the principles of physics. This model can be made more accurate by including in it perturbations such as drag and solving for parameters that help define the effect of these perturbations on the position as a function of time.

Of course, the more parameters in the state, and the more complex the model, the more data is needed to find a solution. Once a model including dynamics is defined, data at different times may be used, so there is generally more data available than the minimum needed to find a unique solution. In such ‘over determined’ cases, especially when the observations are uncertain, least-squares or other estimation techniques are used to find the best state to match the observations to the model solution.

The process can be generalized to the following four steps:

1. A set of measurements is acquired.
2. The set of measurements is fit to a dynamic model to provide a solution state (cf. references [8], [13], and [14]).
3. The solution state is used in the model to predict the future state.
4. If necessary, the spacecraft state is altered at some future time:
5. For trajectories/flight paths: A spacecraft propulsive maneuver is performed to correct the trajectory, if necessary, to meet mission requirements and constraints. This process is called ‘flight path control’.
6. For attitudes: A maneuver is performed to modify the spacecraft attitude, if necessary, to meet mission requirements and constraints. This process is called ‘attitude adjustment’.

The process is illustrated in figure 2‑1 (next page).



Figure 2‑1 : The Navigation Process

Figure 2‑2 depicts the spacecraft navigation process, which can take place either in real time, near–real time, or after the fact (also referred to as reconstruction).

Measurements taken

Now

Measures interval

State determination

Now

Measures interval

State prediction

Now

Measures interval

Prediction

Figure 2‑2 : Real-Time or Near–Real-Time Navigation Process