BS ISO 23339:2010

BSI Standards Publication

Space systems — Unmanned spacecraft — Estimating the mass of remaining usable propellant

National foreword

This British Standard is the UK implementation of ISO 23339:2010.

Although this standard contains requirements for estimating the amount of usable propellant on unmanned spacecraft in order to enable end-of-life disposal manoeuvres, some of the content of the standard may overlap, or be at variance with, the top-level space debris mitigation standard BS ISO 24113 and the flow down of requirements to other debris mitigation standards. In the event that such a circumstance should arise, the UK committee recommends that BS ISO 23339 should not take precedence.

The UK participation in its preparation was entrusted to Technical Committee ACE/68/-/3, Space systems and operations - Operations and Ground Support.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Foreword

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ISO 23339 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

This International Standard acts as one of the supporting technical standards for orbital debris mitigation.

For spacecraft disposal manoeuvres to be performed as planned, the estimation of available propellant mass is essential. The aim of this International Standard is, through requirements for the estimation of remaining propellant, to improve spacecraft disposal techniques and thereby mitigate orbital debris.

Space systems — Unmanned spacecraft — Estimating the mass of remaining usable propellant

1 Scope

This International Standard gives requirements for estimating the mass of the remaining usable propellant of an unmanned spacecraft in low Earth orbit (LEO) or geostationary Earth orbit (GEO), and for designing propellant measurement systems. It is applicable to spacecraft with either mono- or bi-propellant propulsion systems using liquid or gaseous chemical propellants, and is limited to such systems because they are the most common for spacecraft in LEOs and GEOs.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 24113, *Space systems — Space debris mitigation requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 24113 and the following apply.

3.1
book-keeping method
method for determining fluid consumption by monitoring flow rates and the duration of propellant expenditure periods

3.2
disposal manoeuvre
orbital manoeuvre that disposes of a spacecraft from the protected regions by either decreasing or increasing the altitude of the spacecraft

3.3
PVT method
method for determining the remaining mass of gas by deriving density in a known volume from pressure and temperature measurements

NOTE PVT: pressure, volume, temperature.

3.4
remaining usable propellant
propellant that remains in the propellant system and that is effective for attitude and orbit control manoeuvres

3.5
orbital debris
space debris
all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional

3.6
spacecraft
system designed to perform specific tasks or functions in space

NOTE A spacecraft that can no longer fulfil its intended mission is considered non-functional. Spacecraft in reserve or standby modes awaiting possible reactivation are considered functional.

4 Objectives

4.1 General

Orbital debris could cause substantial damage to other spacecraft, space stations, shuttles, etc. Orbital debris include non-functioning payloads or used launch vehicle upper stages. The steady increase in orbital debris increases the risk of collision, which creates more debris in orbit. Disposing of spacecraft at EOL (end of life) reduces the risk of collision and increases safety. For the active disposal manoeuvre of a spacecraft at the end of mission, there usually has to be enough propellant for the manoeuvre. The amount of propellant is typically a key design parameter that determines the on-orbit lifetime.

In order to reserve enough usable propellant to ensure the success of disposal manoeuvres, the propellant used over life shall be estimated with stated uncertainty and the remaining usable propellant shall be regularly monitored with quantified uncertainty.

4.2 Objectives in estimating mass of remaining usable propellant

The prime objectives in estimating the mass of remaining usable propellant are

a) to ensure the successful disposal of the spacecraft, and

b) to drain the propellant system in order to remove a potential source of energy for creating additional secondary debris caused by any primary debris impact.

For debris mitigation, successful venting of residual propellant is often required at end of life and tends to be favoured by minimizing the amount of remaining propellant.

5 Requirements

5.1 Selection of estimation method

The estimation method (and allowances for estimation error) that best meets the objectives outlined in Clause 4 shall be selected at an early stage of the spacecraft design phase and mission development. The use of multiple estimation methods is recommended for redundancy and higher certainty. Annex A lists estimation methods suitable for applicable spacecraft.

5.2 Estimation of propellant mass

The needed propellant amount and error shall be estimated at the design phase. Propellant mass and volume determine the spacecraft bus characteristics in size and mass, and influence the launch cost as well. A careful consideration of the estimation error of remaining usable propellant at the design phase can optimize the design and reduce the propellant loading amount.

During the on-orbit mission phase, the actual mass of remaining usable propellant shall be monitored regularly over life to ensure that a positive margin of usable propellant remains to perform the disposal manoeuvre as planned. The margin shall include a mass equivalent to the assumed estimation error.

The above stated requirements of this subclause shall be performed through the following process steps.

a) Produce an initial propellant budget in the design phase, including all errors and margins to allow safe disposal.

b) Refine the budget throughout the design/build process as better mass and delta-V budgets become available.

c) Use the final propellant budget to define loaded propellant mass.

d) Monitor and evaluate the propellant mass remaining throughout the mission at regular intervals.

e) Compare the usage rate with the mission plan. If propellant is being consumed at a greater rate than planned, the mission plan shall be changed to ensure there will still be sufficient propellant remaining to perform the planned disposal manoeuvre

5.3 Uncertainty of estimation

The measurement uncertainty estimation shall account for all significant error contributions. The error contributions shall be expressed as equivalent propellant amounts, typically in kilograms. Examples of error contributing parameters are given in Annex A.

When several methods are available after taking account of cost, mass, performance, etc., the optimal measurement or set of measurements should be used, considering that different kinds of measurements are best for each mission phase (early operation, partially consumed, nearly empty).

Designers may choose between low-cost, coarse sensors and expensive, very precise sensors. Measurement uncertainty estimation shall reflect, as an additional propellant mass loading, its estimation error as well as the particular characteristics of the propulsion system, its performance and the planned propellant consumption.

5.4 Incorporating required function into spacecraft design

After the estimation method or methods have been selected, the hardware and software required to estimate the mass of remaining propellant and to record, store and transmit the associated data shall be incorporated into the system design.

The hardware and software design features required to estimate the mass of remaining propellant shall be assessed throughout the spacecraft's development. The functions of hardware and software required to estimate the mass of remaining propellant shall be verified at the test phase. If this cannot be verified in the ground test environment, alternatively it shall be verified by analysis to assure the functionality in space. The accounting of degradation of the overall measuring system over the mission life shall also be required. The mass of remaining propellant shall be re-estimated as necessary parameters are determined and their contributions to error become clear. The amount of propellant estimated as being necessary for the disposal manoeuvre (including the measurement uncertainty) shall be determined before launch and loaded on the spacecraft. The required propellant measurement uncertainty shall be specified and evidence shall be available to justify that the design will meet this requirement throughout the spacecraft's nominal life.

EXAMPLE Pressure and temperature sensors for monitoring the tank conditions are essential for the PVT method whereas thrust history data are crucial for the book-keeping method.

5.5 Documentation of data

The data necessary for estimating the remaining usable propellant mass shall be documented throughout the manufacturing, testing and on-orbit mission phases. The data shall include the estimation error relating to each parameter. The data acquired through the testing phase shall be described in the satellite handbook and shall be able to be referenced at the operation phase.

A measurement of available propellant shall provide the following information:

a) the time at which the measurement applies;

b) the estimated amount of available propellant in units chosen by the user;

c) the uncertainty on this estimate to a confidence level chosen by the user and in the same units as the measurement (e.g. 95 % confidence that the actual amount of propellant is within x kg of the reported measurement), which shall be evaluated using a technique supported by documented evidence;

d) a note of any significant issues relating to the use of the reported measurement.

EXAMPLE The measurement is based on the book-keeping method and was made just after a standard orbit maintenance burn.

NOTE See Annex A for examples of key parameters to be documented for each estimation method.

The measurement uncertainty of, for example, a pressure sensor shall be documented at the design phase, at the component test level and, finally, at the system test level, in order to evaluate its contribution to the estimated remaining usable propellant value.

Annex A
(informative)

Examples of estimation methods

Table A.1 gives examples of estimation methods typically used in propulsion systems using liquid or gaseous chemical propellants.

Table A.1 — Examples of estimation methods (reproduced with permission from Reference [2], © ESA)

Method	Used for	Measurement Principle	Advantages and Disadvantages	Heritage / Development Status
pVT	3axis + spinner	Measurement of the tank temperature and pressure and calculation of the tank ullage volume and thereby the remaining propellant mass by applying the gas law.	+ no additional equipment and lowest costs - decreasing accuracy towards EOL, low accuracy with conventional pressure transducer	used on many spacecrafts
Thermal Knocking	3axis + spinner	Heating of the propellant tank and measurement of its thermal response which is related to the propellant load.	+ no additional equipment - low accuracy, high calibration efforts and long operational gauging times	used on • OLYMPUS • EUROSTAR
Gas Injection	3axis	Transfer of a known amount of pressurant gas into the propellant tank and measurement of the pressure and temperature increase to determine the ullage volume and thereby the remaining propellant mass	+ good accuracy at EOL - complex system, modification of propulsion system required, needs high accuracy pressure transducer, high calibration effort and high costs	• ground qualification of an Engineering Model Gauging Device[1] • operational use of Hughes Propellant Gauging System[2] • in-flight demonstration of Foreign Mass Injection Method and Periodic Volume Stimulus Method[3]
Liquid Leveling	spinner	Measurement of liquid level in tanks of satellites where propellants are settled due to spin acceleration.	+ simple system with very high accuracy - limited to spinning satellites	used on : • MSG (capacitive measurement) • Hughes (Δp measurement)
Bookkeeping	3axis + spinner	Calculation of propellant consumption during each maneuver by on-ground recording of all maneuver data (e.g. pulse duration, pulse mode, thruster temperature). making additionally use data of individual thruster calibration test firings on ground.	+ simple system with no additional equipment needed - inflight calibration required, operational effort on ground	used on many spacecraft
Flowmeter	3axis	Integration of thruster mass flowrate measurements during operation.	+ high accuracy - sensor still to be developed, low accuracy for pulse firings	CNES funded spatialisation of a thermal flowmeter failed in 1990 due to sensitivity to gravity vector, thermal environment and small gas bubbles in flow. ESA/ESTEC development of an ultrasonic flowmeters.
Liquid Leveling	3axis	Measurement of liquid level in tank during thruster operation.	+ accuracy improvement feasible - low achieved accurcay, works only during thruster firings of a minimum thrust level and duration	used on • Apollo • Shuttle OMS

NOTE “Thermal knocking” is also called “thermal gauging”.

Table A.2 shows examples of key parameters to be documented, for the two methods generally used on LEO and GEO satellites.

Table A.2 — Examples of key parameters

Method	Key parameters
Book-keeping method	Propellant mass flow rate, m
	Each thruster's on-time, t
	Thrust
	Specific impulse
	Bipropellant mixture ratio
	Propellant consumption (= $m \times t$)
	Thrust estimation error
	Specific impulse estimation error
	Mixing ratio estimation error
	Propellant loading error
PVT method	Pressurant gas amount in tank
	Pressurant gas pressure
	Pressurant gas volume
	Pressurant gas temperature
	Tank volume
	Pressurant gas pressure measurement error
	Pressurant gas temperature measurement error
	Propellant density
	Oxidizer density
	Bipropellant mixture ratio
	Propellant loading error

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[4] LAL, A. and RAGHUNADAN, B.N., Uncertainty Analysis of Propellant Gauging System for Spacecraft, *Journal of Spacecraft and Rockets*, Vol. 42, No. 5, September–October 2005

1) ESA/ESTEC (European space agency/European space research and technology centre).

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