Rafael Space Propulsion

CATALOGUE

A

B

C

D

E

F

G

RAFAEL
SMART AND TO THE POINT

Rafael Space Propulsion

INTRODUCTION AND OVERVIEW

Heritage

Heritage

PART A

Rafael Introduction and Overview

Rafael Advanced Defense Systems Ltd. designs, develops, manufactures and supplies a wide range of high-tech systems for air, land, sea and space applications.

Rafael was established as part of the Ministry of Defense more than 70 years ago and was incorporated in 2002. Currently, 7% of its sales are re-invested in R&D. Rafael's know-how is embedded in almost every operational Israel Defense Forces (IDF) system; the company has a special relationship with the IDF.

Rafael has formed partnerships with companies with leading aerospace and defense companies worldwide to develop applications based on its proprietary technologies. Offset activities and industrial co-operations have been set-up with more than 20 countries world-wide. Over the last decade, international business activities have been steadily expanding across the globe, with Rafael acting as either prime-contractor or subcontractor, capitalizing on its strengths at both system and sub-system levels.

Rafael's highly skilled and dedicated workforce tackles complex projects, from initial development phases, through prototype, production and acceptance tests. Rafael offers a full range of customer service and support, from upgrading of existing systems up to turnkey projects, from transfer of basic technologies to complete production facilities.

Rafael's quality management system is certified to AS9100C (AS9100D in process), ISO9001, ISO14001, ISO27001, ISO90003, OHSAS 18001.
The environmental tests facilities, metallurgy laboratory and calibration laboratory are certified to ISO17025

Rafael aims to enhance its acclaim as a world-class provider of quality defense products and excellent customer service. It will continue to predict future aerospace requirements worldwide and provide the technologies and systems required by our customers.

Manor Advanced Defense Technology Division

The Manor Advanced Defense Technologies Division develops and manufactures propulsion systems, composite materials, and pyrotechnic devices for all Rafael's systems, as well as for domestic and international customers.

Manor Division is engaged in every aspect of product development and manufacturing, from specification and design to manufacturing and integrated logistics support.

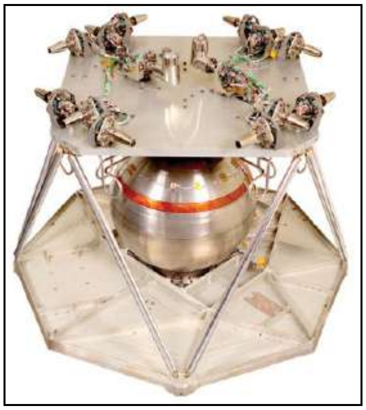
Comprehensive analytic tools and facilities are available in-house, covering all aspects of research, design, development, manufacturing and testing of solid and liquid propellant rocket motors, hydrazine mono-propellant space propulsion systems electric space propulsion systems as well as propellant reservoir tanks.

Manor Division possesses the infrastructure necessary for the research, development and production of solid and liquid propellant rocket motors, their components and, in some cases, the raw materials. Modern computerized laboratories have been set up for synthesis and characterization of advanced binders, bonding agents, burning rate catalysts and other propellant ingredients.

Manor's testing facilities include a variety of computerized static firing cells, including a high-altitude and space simulation cells, as well as environmental testing facilities.

Heritage PART A

Rafael's Space Capabilities



Rafael's space activities are focused on Space Propulsion, Composite materials, Micro-Satellite technologies and airborne launchers.

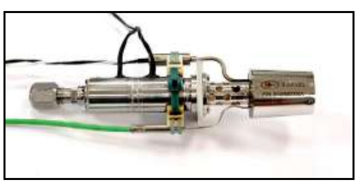
Rafael has gained extensive experience in developing, qualifying and producing controllable propulsion and reaction control systems, based on both hot gas (gas generators, solid rocket motors and hydrazine thrusters) and cold gas (mainly nitrogen) for space applications.

Rafael propulsion modules or components are integrated in over seventy in-orbit satellites. Rafael complete propulsion modules are on board the OFEQ, EROS, TecSAR and other satellites. Rafael furnished the propellant tanks and hydrazine thrusters for the Galileo IOV, Globalstar-2 constellations, O3B constellations, SENTINEL-1 constellations, NEOSAT, SAC-D, IXV, EXOMARS 2016 and 2020, COSMO SG, CERES, SAOCOM and others.

Rafael joint CNES\ISA dual mission (Scientific / Technological) Venμs satellite, successfully launched in 2017, incorporates Rafael's qualified Electric Propulsion system.

All Rafael propulsion systems and components in space have demonstrated 100% mission success, with no system or component failures, or loss of redundancy.

As part of its long-term strategy, Rafael invests in micro-satellite-related technologies and concepts, for improved mission solutions. Rafael intends to introduce missile technologies in terms of miniaturization and performance.



Rafael is studying the concept of mission-on-demand, for micro-satellite application, and intends to develop a dedicated airborne launcher that enables using a fighter-aircraft or a jet-liner as launching platform, to enable affordable, flexible mission-on-demand implementation.

Satellite Propulsion Systems (PS):

Hydrazine (HPS), Cold Gas, Electric Hall Effect

	Sat. Program	Product Name	Customer	Comments
1	**OFEQ** OFEQ 3 OFEQ 5 OFEQ 7 OFEQ 9 OFEQ 10 OFEQ 11 OFEQ 16	Hydrazine Propulsion systems (HPS)	IAI/MBT, Israel	1. OFEQ 3, launched in 1995; fully operational in-orbit 2. OFEQ 5, launched in 2002; fully operational in-orbit 3. OFEQ 7, launched in 2007; fully operational in-orbit 4. OFEQ 9, launched in 2010; fully operational in-orbit 5. OFEQ 10, launched in 2014; fully operational in-orbit 6. OFEQ 11, launched in 2016; fully operational in-orbit 7. OFEQ 16, launched in 2020; fully operational in-orbit Their RAFAEL propulsion systems consist of: • 5N / 1N thrusters – 12 or 8 • 25N thrusters – 2 • 30 liters hydrazine tank – 1 (PEPT-420) • Latch valves – 2 • Filters – 2 • Pressure transducers – 2 • Fill and drain/vent valves – 2 • Manifolds, brackets & wiring
2	**EROS** EROS A1 EROS B	HPS	IAI/MBT, Israel	1. EROS A1, launched in 2000; fully operational in-orbit 2. EROS B, launched in 2006; fully operational in-orbit Their RAFAEL propulsion systems consist~~s~~ of: • 5N / 1N thrusters – 12 • 25N thrusters – 2 • 30 liters hydrazine tank – 1 (PEPT-420) • Latch valves – 2 • Filters – 2 • Pressure transducers – 2 • Fill and drain/vent valves – 2 • Manifolds, brackets & wiring

	Sat. Program	Product Name	Customer	Comments
3	**TECSAR**	HPS	IAI/MBT, Israel	TECSAR, launched in 2008 ; fully operational in-orbit The RAFAEL propulsion systems consists of: • 5N thrusters • 25N thrusters • 30 liters hydrazine tank (PEPT-420) • Latch valves • Filters • Pressure transducers • Fill and drain/vent valves • Manifolds, brackets & wiring
4	**GOKTURK -2**	HPS	International customer	GOKTURK-2, launched in 2012 ; fully operational in-orbit The RAFAEL propulsion systems consists of: • 1N thrusters • Latch valves • Filters • Pressure transducers • Fill and drain/vent valves • Manifolds, brackets & wiring
5	**PRISMA**	HPS	OHB-I	PRISMA, launched in 2019; fully operational in-orbit The RAFAEL propulsion systems consists of: • 1N thrusters • 590 liters hydrazine tank (PEPT-420) • Latch valves • Filters • Pressure transducers • Fill and drain/vent valves • Manifolds and brackets

	Sat. Program	Product Name	Customer	Comments
6	**Venμs**	HPS	ISA/CNES	Venμs Satellite, launched in 2017; fully operational in-orbit The RAFAEL Hydrazine Propulsion system consists of: • 1N thrusters – 8 • PEPT-260 hydrazine tank –1 • Latch valves – 2 • Filters – 1 • Pressure transducer – 2 • Fill and Drain/Vent valves – 2 • Manifolds, brackets & wiring
7	**Venμs**	Electric Hall Effect	ISA/CNES	Venμs Satellite, launched in 2017; fully operational in-orbit The RAFAEL Electric Propulsion consists of: • HET-300 thrusters (15 mN @ 300W anodic) - 2 • PPU : 250W to 600W • Xenon tank: 9 liters • DXFC : Digital Xenon Flow Controller • Pressure reduction system and valves

Launcher Propulsion Systems

	Program	Product Name	Customer	Comments
1	**Israeli Satellite Launcher**	RACS 25N Thruster Cluster	IAI/MLM	Successfully launched Each RACS cluster consists of the following components: • 25N thrusters • Valves • Pressure transducer • Manifold • Electronic driver
		RACS 200N Thruster Cluster		Successfully launched Each RACS cluster consists of the following components: • 200N thrusters • Valves • Pressure transducer • Manifold • Electronic driver
		Anti-Nutation Clusters		Successfully launched Each cluster consists of the following components: • 25N thrusters • Valves • Fill - drain valve • Pressure transducer • Manifold • Electronic driver

Propellant Tanks

	Product Name	Customer	Sat. Program	Comments
1	**PEPT-230**	CNES, SNECMA, Astrium-ST	Myriade/AS100 family: • Demeter (x1) • Parasol (x1) • ESSAIM (x4) • Spirale (x 2) • Elisa (x4) • SSTO (X1) • (Future proj. x 4)	1. Demeter, in orbit since 2004 2. Parasol, in orbit since 2004 3. ESSAIM, in orbit since 2004 4. Spirale, in orbit since 2009 5. Elisa, in orbit since 2011 6. SSTO, in orbit since 2011
		SSC	Prisma	Qualified and delivered to the customer, launched 6/2010.
		International customer	GOKTURK-2	Delivered to the customer (part of Rafael HPS), operational in-orbit, launched 12/2012.
2	**PEPT-260**	International customer	Satellite launcher	Qualified and delivered to the customer
		IAI/MBT	Venμs	Qualified and delivered to the customer, launched 9/2017
3	**PEPT-330**	TAS-F	EXOMARS 2016	Qualified and delivered to the customer, launched 3/2016.
4	**PEPT-420**	Thales Alenia Space (TAS), France	PROTEUS • Jason-1 • CALIPSO • COROT • OSTM / Jason-2 • SMOS	PROTEUS family: Jason-1 (12/2001), CALIPSO (4/2006), COROT (12/2006),OSTM/Jason-2 (6/2008), SMOS (11/2009) Fully operational in-orbit
		Astrium-ST, Germany	Giove-B	Operational in orbit (launched 4/2008)
		IAI/MBT	OFEQ	OFEQ - 3, 5, 7, 9, 10, 11, 16 (launched 4/95, 5/02, 7/07, 6/10, 4/14, 9/16, 07/20), Eros (12/00, 4/06)
		IAI/MBT	TecSAR	TecSAR (1/08)
		TAS-F	CERES	3x PEPT-420N type (silica-free diaphragm), delivered to the customer
		AIRBUS	MYRIADE EVOLUTION	2x PEPT-420 type and 4x PEPT-420N type (silica-free diaphragm), delivered to the customer, 1 unit PEPT-420 operational in-orbit

	Product Name	Customer	Sat. Program	Comments
		TAS-UK	NEOSAT	PEPT-420N type (silica-free diaphragm), 5 tanks were delivered to the customer (1 unit operational in-orbit), 1 tank in AIT process
5	**PEPT-590**	Astrium-ST	Galileo IOV (x5)	Qualified and delivered to the customer 4 tanks were launched (10/2011 and 10/2012)
		TAS-F	IXV	Delivered to the customer, launched (2/2015)
		OHB-I	PRISMA	Delivered to the customer, launched (3/2019)
		TAS-UK	EXOMARS 2020	Delivered to the customer (x2)
6	**PEPT-590 GB**	TAS-F	Globalstar-2	Qualified and delivered to the customer (x24), launched between 2010 - 2013
			O3B	Qualified and delivered to the customer (x20), 16 tanks were launched between 2013 - 2018
		TAS-I	Sentinel-1	ST1 A and B delivered to the customer, launched 4/14 and 4/16, respectively ST1 C and D
		TAS-I	COSMO-SG	COSMO-SG 1 and 2 delivered to the customer, COSMO-SG 1 operational in-orbit
7	**GSU-1L**	NRL	Slosh-Sat	Operated in orbit (2/2005) 0.97 Liters (700 bar) – Cold Gas Tank
8	**XPV-260**	CNES/IAI	Venμs	Electric Propulsion Tank, Qualified and delivered to the customer, launched 8/2017

Hydrazine Thrusters

	Product Name	Customer	Sat. Program	Quantities/Comments
1	**1N Thruster**	Astrium-ST	Galileo IOV	32 units operational in-orbit
		TAS-F	Globalstar-2	96 units operational in-orbit
			O3B	128 units (of 160) operational in-orbit
			NEOSAT	48 units Delivery to the customer in-process, 8 units operational in-orbit
		TAS-I	Sentinel-1	28 units operational in-orbit (ST1 A & B), 28 units (ST1 C & D) were delivered to the customer
			COSMO-SG	12 units were delivered to the customer (COSMO-SG 1 & 2, COSMO-SG 1 units operational in-orbit), 12 units in AIT process (COSMO-SG 3 & 4)
		IAI	Venμs	8 units operational in-orbit (part of Rafael HPS)
		OHB-I	PRISMA	2 units delivered to the customer (part of Rafael HPS), operational in-orbit
		International customer	GOKTURK-2	Delivered to the customer (part of Rafael HPS), operational in-orbit
		OHB-I	KORESAT	32 units in AIT process
		CONAE	SABIA-MAR	10 units in AIT process
		CONAE	SAC-D	8 units were delivered to the customer
2	**5N Thrusters**	IAI/MBT, Israel	OFEQ EROS TECSAR	More than 100 units were supplied Fully operational in-orbit
		CONAE	SAOCOM	44 units delivered to the customer (part of Rafael Dual Thruster Module - DTM), operational in-orbit
3	**25N Thrusters**	IAI/MBT, Israel	OFEQ EROS TECSAR	More than 27 units were supplied Fully operational in-orbit
4	**25N RACS Thruster Cluster**	IAI/MLM	Israeli Satellite launcher	Operational in-orbit
5	**45N Thrusters**	International customer	Satellite launcher	Qualified and delivered to the customer

	Product Name	Customer	Sat. Program	Quantities/Comments
6	**200N RACS Thrusters Cluster**	IAI/MLM	Israeli Satellite launcher	Operational in-orbit

Propulsion System Valves

	Product Name	Customer	Sat. Program	Comments
1	**Latch valves**	IAI	OFEQ EROS TECSAR	Delivered to the customer (part of Rafael HPS), operational in-orbit
		International customer	Satellite	Qualified and delivered to the customer
		International customer	GOKTURK-2	Delivered to the customer (part of Rafael HPS), operational in-orbit
		OHB-I	PRISMA	Delivered to the customer (part of Rafael HPS), operational in-orbit
2	**FDV** **Fill and Drain valve**	IAI	OFEQ EROS TECSAR	Delivered to the customer (part of Rafael HPS), operational in-orbit
		International customer	Satellite	Qualified and delivered to the customer
		International customer	GOKTURK-2	Delivered to the customer (part of Rafael HPS), operational in-orbit
		OHB-I	PRISMA	3-barriers FDV type, Delivered to the customer (part of Rafael HPS), operational in-orbit
3	**FVV** **Fill and Vent valve**	IAI	OFEQ EROS TECSAR	Delivered to the customer (part of Rafael HPS), operational in-orbit
		International customer	Satellite	Qualified and delivered to the customer
		International customer	GOKTURK-2	Delivered to the customer (part of Rafael HPS), operational in-orbit
		OHB-I	PRISMA	Delivered to the customer (part of Rafael HPS), operational in-orbit

Satellite Propulsion Systems

Hydrazine

EPS - Electrical Propulsion System – Medium Power

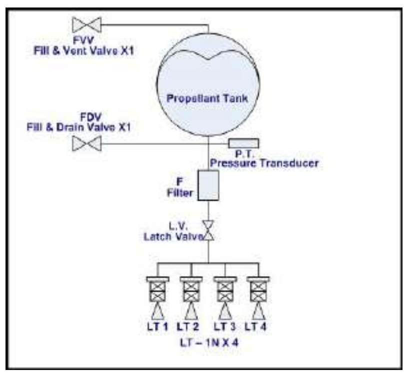
Hydrazine Propulsion System

Satellite Propulsion Systems

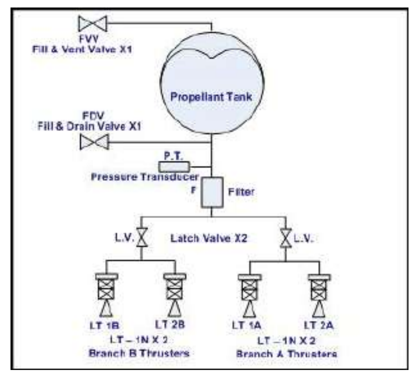
The Satellites Space Propulsion Systems are typically used for correction of orbit insertion errors and for orbit maintenance.

The monopropellant propulsion systems may typically use one of the following main architectural concepts:

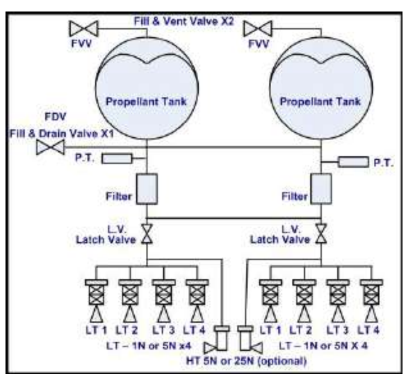
- Single branch propulsion, versus dual- branch (redundant) propulsion.
- Low-thrust thrusters (5N or 1N), or high-thrust thrusters (25N).



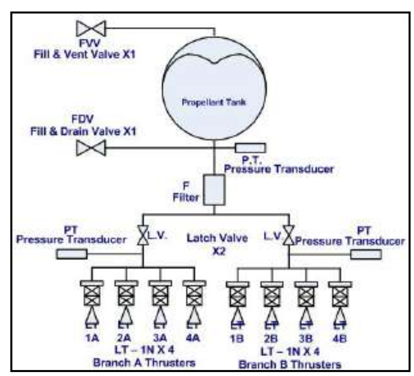
Four thrusters, single-branch propulsion system architecture



Four thrusters, dual-branch (redundant) propulsion system architecture



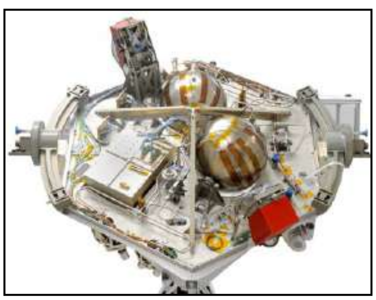
Dual-Tank & dual branch propulsion (redundant) architecture with eight thrusters

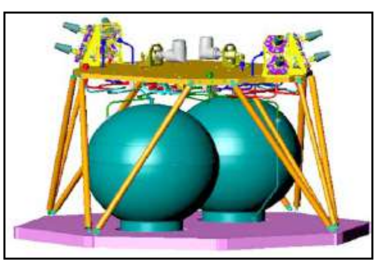


Dual-branch (redundant) propulsion architecture with thrusters and PTs at branch-level

Sat. Propulsion Systems PART B

Hydrazine Propulsion System





Architecture

The Propellant is loaded into the tank through a fill and drain valve (FDV).

The pressurant gas is filled into the opposite side of the tank through a fill and vent valve (FVV).

A flexible EPDM diaphragm separates between the propellant and the pressurant Inside the Tank.

The tank maintains a gas pressure ratio of 4:1 (BOL/EOL).

A pressure transducer installed on the propellant line enables monitoring the propellant pressure which indicates the residual propellant quantity during the mission.

The latching valves (LV), provide an additional mechanical barrier for the hydrazine to meet the launch safety requirements and enables the option to disconnect the relative branch in case one of the thrusters fails throughout the mission.

Once the latch valve is switched to OPEN, the pressurized propellant may be expelled towards the thrusters. Integral dual-seat dual-coil normally-closed flow control valves (FCV) control the propellant flow into the thrusters; thus the design satisfies the common three-barriers requirement.

The pressure transducer is used throughout the service life of the satellite to estimate the residual hydrazine level; the pressure level is used by the control system as a parameter for estimating the available thrust.

The system architecture is selected according to mission and reliability considerations.

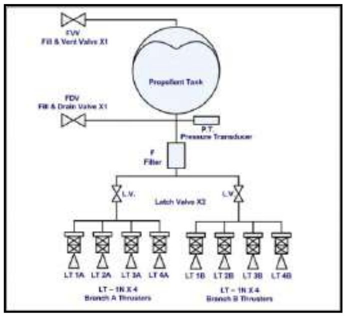
The use of redundant twin-branches propulsion significantly increases the system reliability.

The system can include two types of thrusters, High Thrust (HT) or Low Thrust (LT), according to mission requirements. The thrust of the high thrust level thrusters may be chosen as 25N or 5N. The thrust level of the low thrust thruster may be chosen as 5N or 1N.

Differences between the chosen system architectures are derived from the mission and satellite requirements for reliability, lifetime, weight and number of thrusters.

All Rafael propulsion systems and components flown have demonstrated 100% mission success, with no system or component failures or loss of redundancy.

Hydrazine Propulsion System



Dual (redundant) branch propulsion with eight thrusters

Mass Budget of a Typical Propulsion Module (Dry mass)

Group	Component Included	Qty	Unit (kg)	Total (kg)
Propellant Tank PEPT-590	Propellant tank	1	7.5	7.5
Thrusters	LT - 1N thruster	8	0.32	2.56
Propellant Distribution Pipework	F – propellant Filter	1	0.08	0.08
	PT – Pressure Transducers	1	0.25	0.25
	LV – Latch Valve	2	0.4	0.8
	FDV – Fill & Drain Valve	1	0.1	0.1
	FVV – Fill & Vent Valve	1	0.06	0.06
	Tubing (1/4”) /manifolds	1 set	0.6	0.6
Brackets and Thermal Elements	Thruster brackets, component and piping brackets, fasteners and clamps, active thermal blankets, thermostats, thermistors & MLI	1 set	2.5	2.5
Electrical Harness	Wire & connectors	1 set	1	1
Total Dry Mass				≈ 16kg

TECSAR Propulsion System

OFEQ / EROS Propulsion System

Hydrazine Propulsion System

Design Considerations and ICD

During the design phase of the Propulsion System (PS) all the relevant considerations related to the satellite are taken into account, such as:

- Mechanical interfaces and mass budget
- Electrical interfaces, power consumption and control commands
- Thermal control, heat dissipation and radiation budget.

Mechanical Interfaces

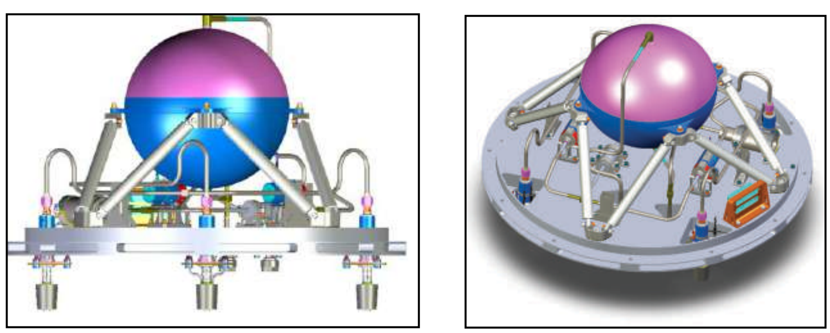
The propulsion system components (e.g. tank, thrusters, LV, FDV/FVV, Manifolds, etc.) are installed on the satellite structure.

Two basic concepts of a PS components installation are available.

- On a dedicated base plate
- Dispersed at various locations in the satellite.

In the case of using a dedicated base plate concept, the base plate itself may be supplied by Rafael, or by the Customer. The PS, together with the base plate, is installed as a plug-in module to the satellite.

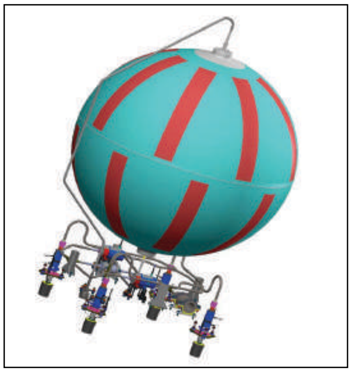
The tank can be installed, held at the equator or poles, on the base plate or struts, subject to project requirements.



Plug-In Propulsion System

Sat. Propulsion Systems PART B

Hydrazine Propulsion System



Electric Interfaces

Rafael provides full electric interface for the Propulsion Systems. A typical PS electrical design includes the electrical harnesses which perform the link of command lines between the satellite and the active elements of the PS.

Electric wires, in accordance with space standards, are routed to on-board electrical devices. All splices, shrinks, crimps, lacing and soldering comply with ECSS-Q-70-08A.

Typical PS uses regulated (28±4 VDC typical) and unregulated voltage (25 to 45 VDC). The regulated voltage is supplied to the PS valves (FCV's, LV). The unregulated voltage may be used for the subsystem heaters.

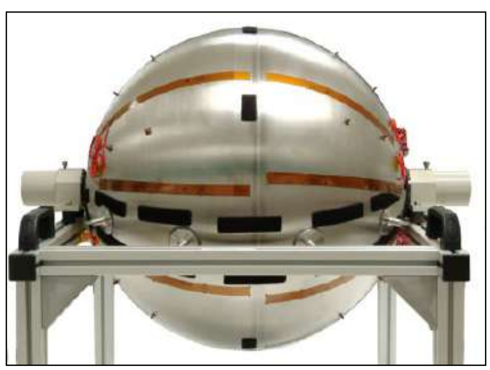
Rafael performs overall electrical tests and provides a ready-to-connect plug-in module to the Satellite.

Thermal Control

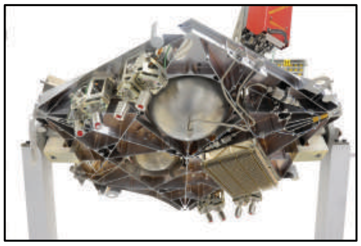
Rafael is capable of delivering an all-around full thermal control solution as an integral part of the propulsion system.

Rafael's expertise is available for tanks as well as for thruster FCVs and for pipes; the capabilities include thermal analysis, thermal control design with redundancy options, specification of heating requirements, determining locations for heating elements (thermostats, thermistors) and use of thermocouples for heat measurement of thruster TCAs.

The heating controllers are governed by the satellite's main control unit.



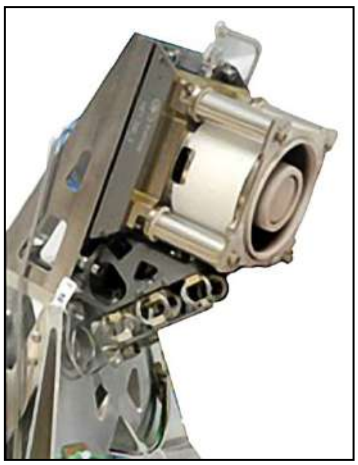
Electric Propulsion System



Rafael designs, develops and manufactures Electric Propulsion Systems (EPS).

The Venµs satellite (a CNES & ISA cooperation) was launched in 2017. Rafael supplied its EPS, which is successfully operating since and gaining heritage.

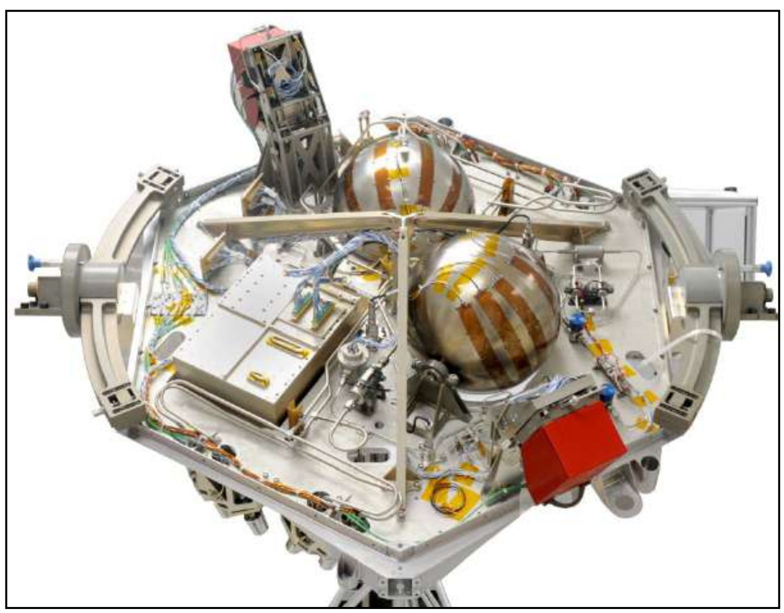
The Rafael EPS for the Venµs satellite is designed to support and operate two IHET-300 Hall-Effect thrusters (HET), designed for low-power operation.



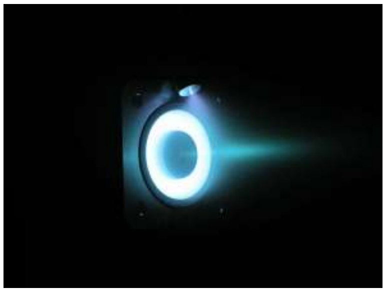
Venµs EPS's main components are the 2 Hall-Effect Thrusters, Propellant Management Assembly (PMA), Digital Xenon Flow Controller (DXFC), Power Processing Unit (PPU), and 2 Filter Units (FU).

The PMA is composed of a tank, storing up to 16kg of high pressurized Xenon, and of a set of valves, pressure reducers and manifolds to transport the gas. The PPU comprises the power supplies and the sequencer command logic to operate the thrusters. The FU's function is to filter and to mitigate the thruster oscillations.

For missions requiring thrust flexibility, a variable thrust mechanism is incorporated. The Rafael EPS incorporates a DXFC that serves as the "throttling" device for the xenon flow rate through the HET-300 anode.



R-800 EPS Electric Propulsion System



The R-800 EPS is an electric propulsion system operating in the 450-900 W power range. The system consists of a Hall thruster unit, Power Processing Unit (PPU) and Propellant Management Assembly (PMA). The propulsion system is based on Rafael's R-800 Hall Effect Thruster. The R-800 EPS is Rafael's second-generation EPS system following the Space-Qualified R-400 EPS (Venµs EPS) success.

The R-800 thruster has recently completed its qualification. Lessons learned during its initial development led to many improvements that were implemented with the purpose of producing a lighter-weight, electrically and mechanically robust thruster capable of operating in the expected environment of space. The thruster, including its corresponding low current heaterless hollow cathode – completed the qualification process during which it underwent a full performance test, shock and vibration test and was operated in an endurance (lifetime) experiment. In addition, the thruster's operational envelope was tested at power levels from 450 W and up to 1350 W, to verify operation robustness. The thruster was operated both on Xenon and Krypton propellants.

Typical mission applications of the R-800 EPS include:

- Orbit keeping and drag compensation for LEO, down to altitudes below 350 km.
- Enabling formation-flying missions of small-satellites.
- Accurate and precise final orbit insertion after separation from launcher.
- Mission orbit change and disposal deorbit at end of life.

Propellant Tanks

Component	Tank Nominal Volume [Liter]	Qualified Propellant Capacity [Liter]
PEPT- 200	3.55	3.3
PEPT- 230	6	4.5
PEPT- 260	9.3	7
PEPT- 330	17.5	15.4
PEPT- 420N	37.5	30
PEPT- 590	102.5	75
PEPT- 590GB	204	154

Note: The tanks can be partly filled in all configurations up to the full propellant capacity due to the use of a diaphragm as propellant management device.

Positive Expulsion Propellant Tank – General Description

Rafael's Positive Expulsion Propellant Tank (PEPT) is made of 2 6Al-4V titanium alloy thin-walled hemispheres (optionally with a cylindrical mid-section extension). Positive fuel expulsion is provided by an EPDM-based rubber diaphragm retained between welded parts inside the tanks. Pressurant and propellant ports are weldable, 1/4" titanium tubes.

The Propellant Tank is made of the following segments:

- Lower hemisphere
- Upper hemisphere
- Cylindrical extension section – optional
- EPDM-based, silica-free rubber diaphragm

Integration to a complete tank is accomplished through peripheral Electron Beam Welding (EBW).

The hemispheres are hot-formed and machined to final dimensions. The design of the hemispheres enables the incorporation of integral pressurant and propellant ports.

The diaphragm has a 15 years life expectancy with hydrazine inside and has been qualified for various missions and satellite busses, such as Globalstar2, Myriade, Proteus, Galileo, Exomars, Neosat, OFEQ and others. The diaphragm has been qualified for use with ADN-based "green" propellant.

Diaphragm Propellant Management Device

The diaphragm allows active and efficient propellant management throughout the satellite’s lifetime. It allows multiple cycles of filling and emptying, simulation tests, as well as system integration and other tests.

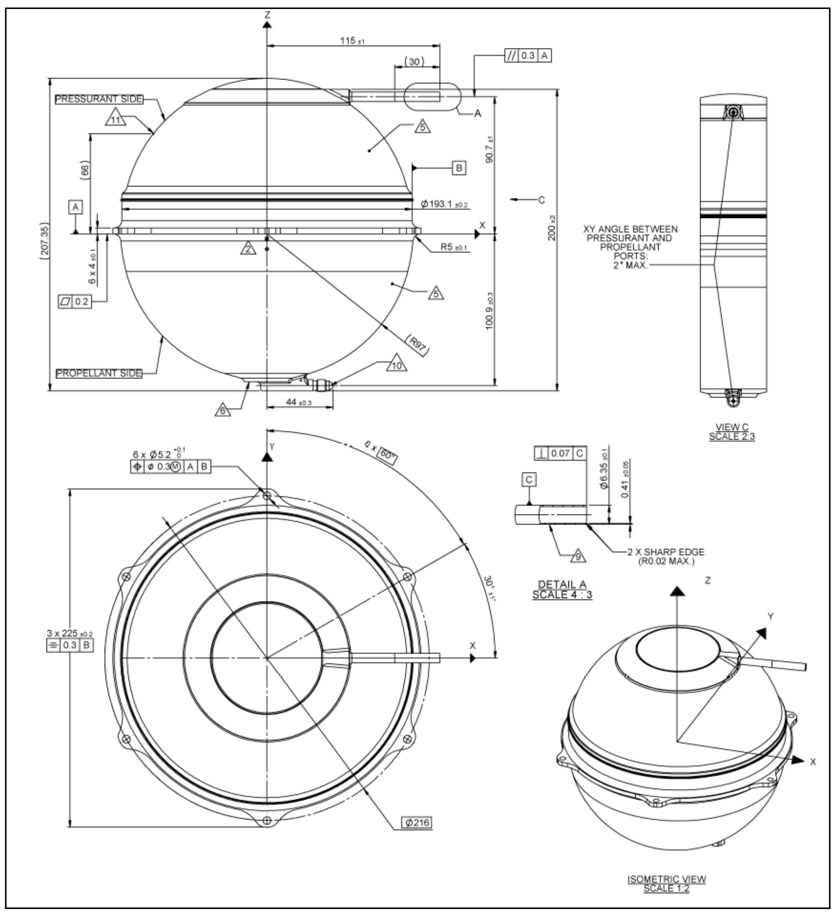
In contrast to a surface tension-based propellant management device, a tank equipped with a diaphragm does not limit the degree of filling in any of the operational stages.

The tank may be partially filled to any degree, including prior to horizontal transportation on the launch pad, and the necessary gas-free propellant feed is assured for any subsequent demand. Another advantage is superior control over liquid sloshing.

This superior propellant management by diaphragm prevents undue sloshing loads which might adversely affect satellite stability during launch and maneuvers in space, as well as propellant feed which is made free of any limitations caused by satellite orientation, movement, or acceleration. Positive expulsion by the diaphragm prevents excessive center-of-gravity shift as caused by propellant movements in surface tension or bladder type tanks during satellite maneuvers, thus preventing excessive attitude-control system requirements.

Rafael's diaphragm material is **silica free** (no SiO_2) enabling better performances of the PS thruster.

PEPT- 200

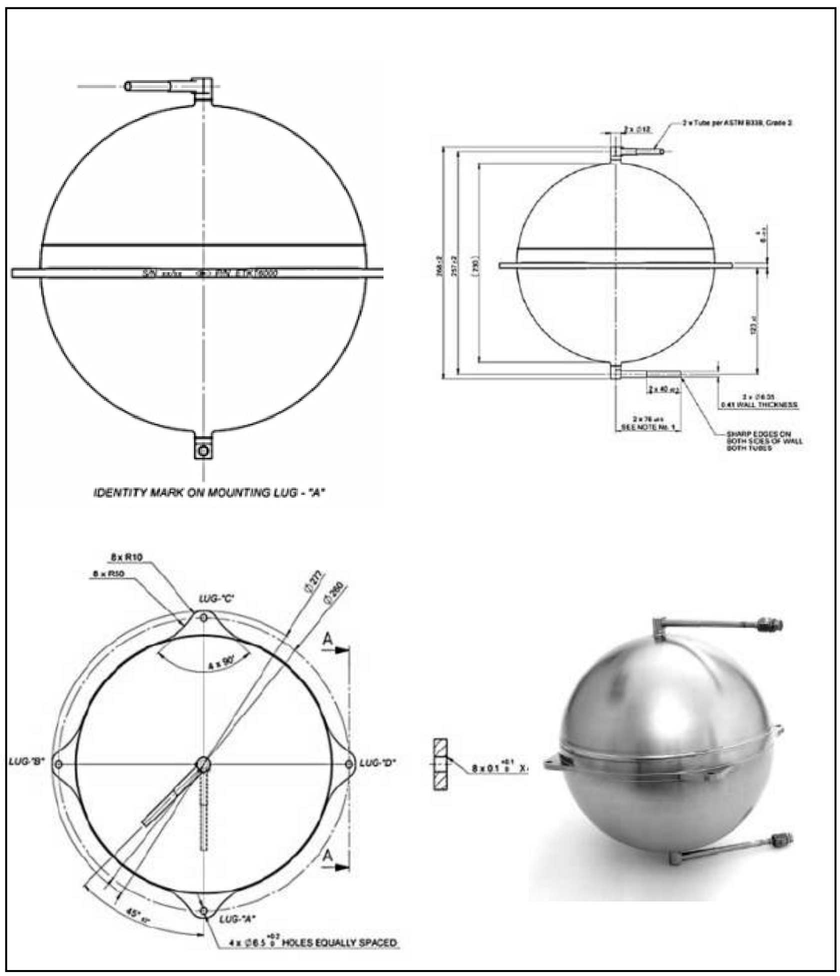


PEPT-200

PEPT-200 Main Characteristics

Parameter	Data
Configuration	Spherical, ~200 mm OD
Fluid Media Compatibility	Hydrazine, IPA, distilled water, GN2, GHe
Nominal Volume	>3.55 [L] Unpressurized
Max Propellant Capacity	3.3 [kg]
Volumetric Expulsion Efficiency	≥ 99.1 [%]
Internal Pressure	
MEOP	32 [bar] @ 50 [℃]
Proof	48 [bar]
Required burst	> 64 [bar]
Internal Leakage	≤ 4.0 x 10^{-3} [Scc/sec GHe]
External Leakage	≤ 1.0 x 10^{-6} [Scc/sec GHe]
Materials	
Tank's shell	Ti-6Al-4V, Annealed
Diaphragm Material	EPN-40, Silica free elastomer
Ports	Pressurant Port: Ti per AMS4942, 0.25" OD tube for butt welding Propellant Port: Ti-6Al-4V screwed connection per AS4395-02
Mass (dry)	0.91 [kg] ± 0.05 [kg]
Temperatures	
Qualification	+5°C / + 50°C
Service Life	
Storage	5 years
Flight	15 years
Mounting	Equatorial, 6 x Ø5.2 [mm] clearance holes, located on a diameter of Ø216 [mm], equally distributed
Status	Under Qualification

PEPT-230

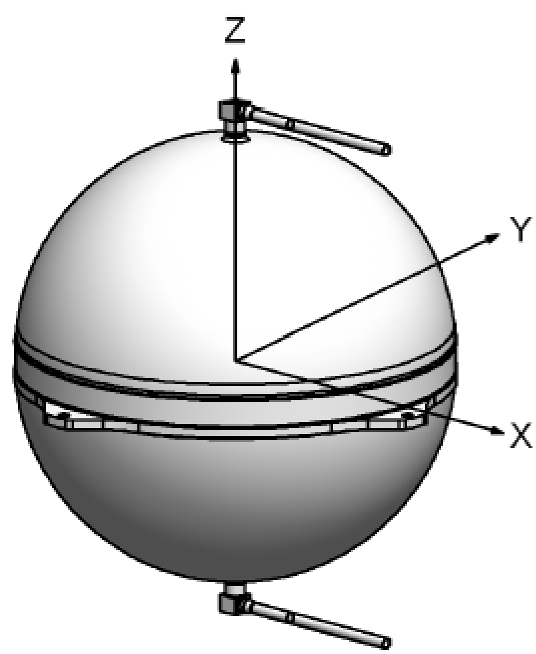


PEPT-230

PEPT-230 Main Characteristics

Configuration	Spherical; nominal ∅230 mm
Fluid Media Compatibility	Hydrazine, IPA, distilled water, GN_2, GHe.
Pressurant	GN_2, GHe, inert gases
Nominal Volume	6 liters
Propellant Nominal Capacity	4.5 liters max @ 4:1 blow-down ratio
Liquid Volumetric Expulsion	>99%
Pressure	
Operating	24 to 5.5 bars. approved for SSC requirement of 400 psi
Proof	36 bars
Burst	48 bars (actual rupture >110 bar)
Leakage	
Internal Leakage	<10^{-2} Scc/sec (GN_2)
External Leakage	<$1x10^{-6}$ Scc/s (GHe) at 24 bars
Material	
Tank Material	Ti- 6 Al-4V
Diaphragm Material	EPZ-63
Ports	ø 1/4” titanium tubes
Weight	<1.3 kg
Temperature	
Operating	10°C to 50°C
Qualification	4°C to 60°C
Service Life	
Storage	7 years
Flight	15 years
Mounting	4 lugs at tank's equator with ø6.5 mm clearance holes (90˚ distribution)
Heritage	Qualified for space applications. (Myriade, Prisma) flight heritage with Myriade and Gokturk-2 satellites in orbit

PEPT-260

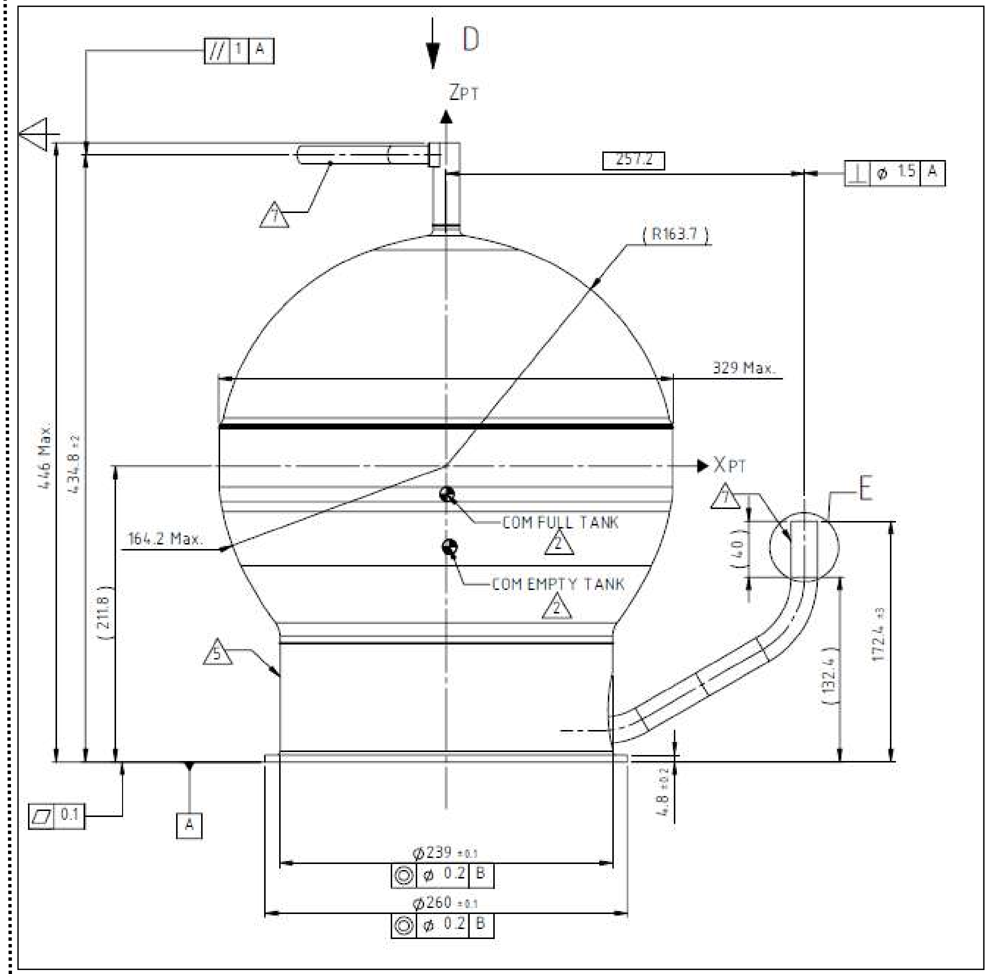


PEPT-260

PEPT-260 Main Characteristics

Configuration	Spherical, nominal ∅260 mm
Fluid Media Compatibility	Hydrazine, IPA, distilled water, GN_2, GHe.
Pressurant	GN_2, GHe, inert gases
Nominal Volume	9.3 liters
Hydrazine Nominal Capacity	7 liters max @ 4:1 blow-down ratio
Liquid Volumetric Expulsion	> 99%
Pressure	
Operating	24 to 5.5 bar
Proof	36 bars
Burst	48 bars
Leakage	
Internal Leakage	$<1x10^{-2}$ Scc/s (GN2)
External Leakage	$<1x10^{-6}$ Scc/s (GHe) @ 24 bar
Material	
Tank Material	Ti-6Al-4V
Diaphragm Material	EPN-40 (Silica Free)
Ports	ø1/4" Ti per AMS4942 tubes, 5" Length
Weight	<1.7 kg
Temperature	
Operating	+10°C to +50°C
Qualification	+4°C to +60°C
Service Life	
Storage	7 years
Flight	15 years
Mounting	4 lugs at tank's equator with ø6.5 mm clearance holes (90° distribution)
Heritage	Qualified for space applications satellite Launcher (international), flight heritage with Venus satellite in orbit

PEPT-330

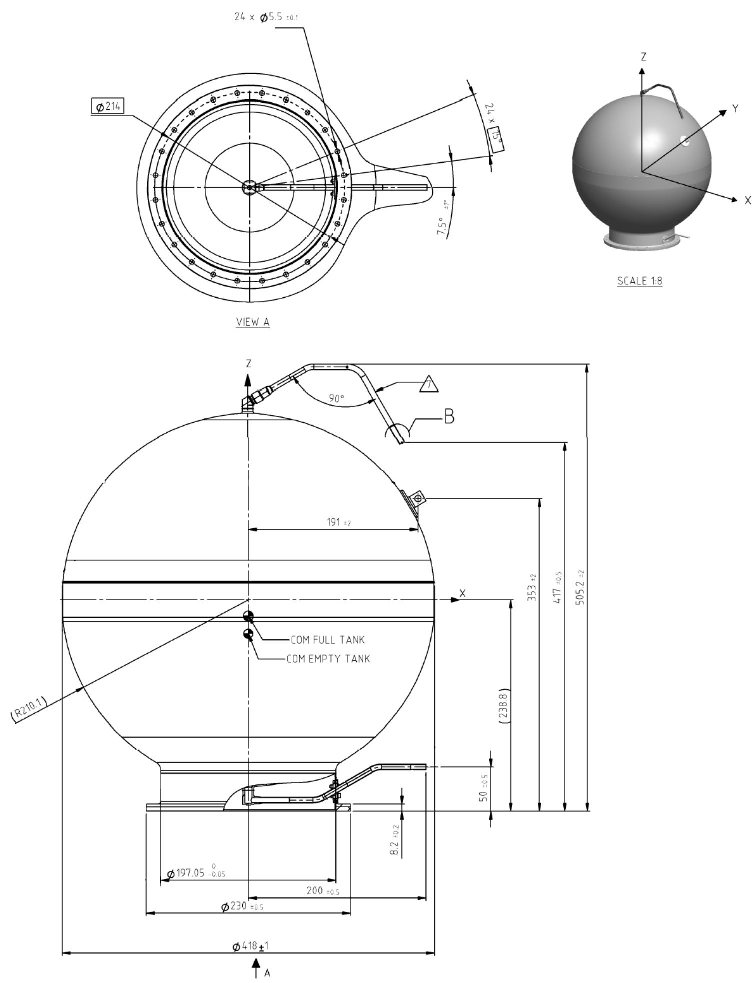

D
ZPT
XPT
257.2
ϕ 1.5 A
// 1 A
(R163.7)
329 Max.
446 Max.
434.8 ±2
164.2 Max.
(211.8)
COM FULL TANK
COM EMPTY TANK
E
(40)
(132.4)
172.4 ±3
4.8 ±0.2
0.1
A
ϕ239 ±0.1
ϕ 0.2 B
ϕ260 ±0.1
ϕ 0.2 B

PEPT-330

PEPT-330 Main Characteristics

Configuration	Spherical, nominal ∅327 mm
Fluid Media Compatibility	Hydrazine, de-ionized water, IPA, GN_2, GHe
Pressurant	GN_2, GHe, inert gases
Nominal Volume	17.5 liter
Hydrazine Maximal Capacity	15.4 kg.
Liquid Volumetric Expulsion	≥ 99.1%
Pressure	
Operating	29 bars (MEOP)
Proof	36.25 bar
Burst	43.5 bar
Leakage	
Internal Leakage	$<1x10^{-2}$ Scc/s (GHe)
External Leakage:	$<1x10^{-6}$ Scc/s (GHe)
Material	
Tank Material	Ti-6Al-4V
Diaphragm Material	EPN-40 - Silica Free
Tank tubes	Ti3Al2.5V
Tubing Interface	Pressuring tube: Ti-3Al-2.5V, 0.5" OD, 0.026" WT Propellant Tube: Ti-3Al-2.5V, 0.75" OD, 0.035" WT
Weight	≤ 3.1 kg
Temperature	
Operating (Qualification):	+4°C to +50°C
Non-Operating (Qualification):	-20°C to +60°C
Service Life	
Storage	7 years
Flight	15 years
Mounting	Pedestal mounting
Heritage	EXOMARS RCS DM

PEPT-420N

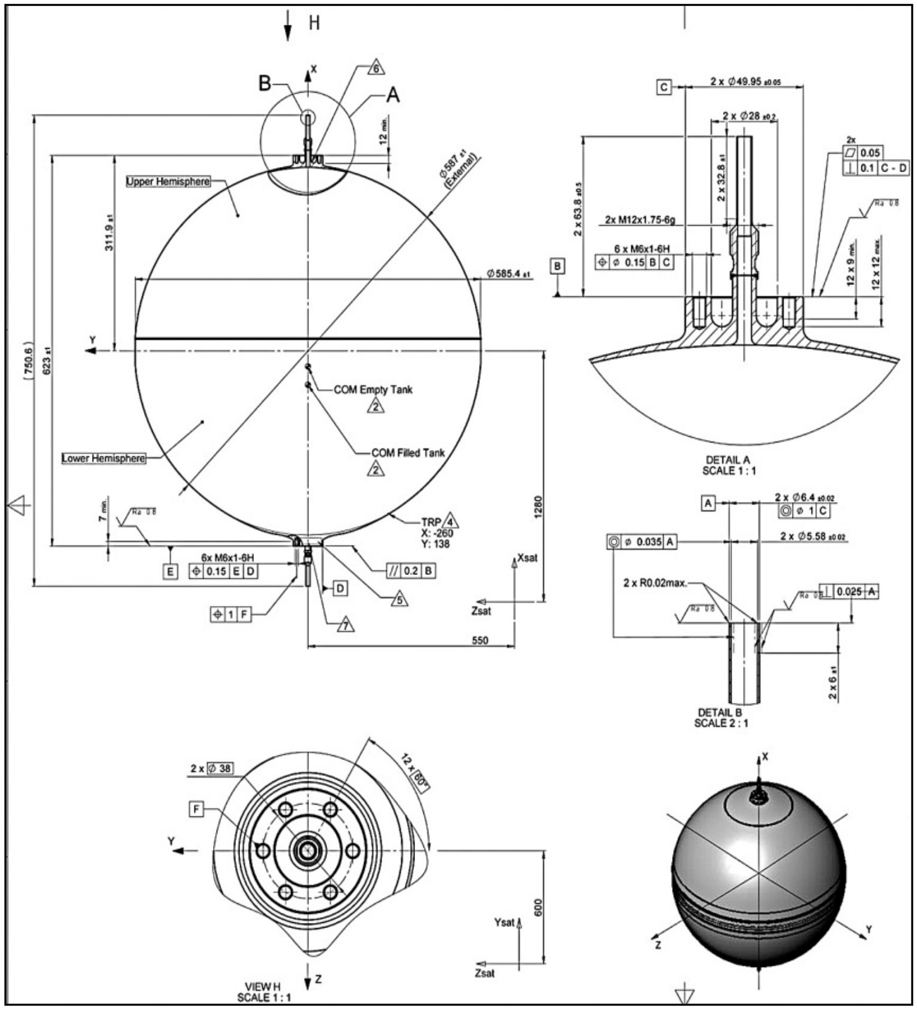

24 x Ø5.5
Ø214
VIEW A
SCALE 1:8
90°
B
COM FULL TANK
COM EMPTY TANK
(R210.1)
Ø418 ±1

PEPT-420N

PEPT-420N Main Characteristics

Configuration	Spherical, nominal ∅420 mm
Fluid Media Compatibility	Hydrazine, distilled water, IPA, GN_2, GHe
Pressurant	GN_2, GHe
Nominal Volume	37.5 liter
Hydrazine Nominal Capacity	30 kg max., 28 kg @ 4:1 blow-down ratio
Liquid Volumetric Expulsion:	≥ 99.0%
Pressure	
Operating	25.4 to 5.5 bar
Proof	38.1 bar
Burst:	58.2 bar
Leakage	
Internal Leakage	$<1x10^{-2}$ Scc/s (GHe)
External Leakage	$<1x10^{-6}$ Scc/s (GHe)
Material	
Tank Material	Ti-6Al-4V
Diaphragm Material	EPN-40: EPDM type silica-free rubber
Ports	ø 1/4" weldable Ti tube or MS 33656-4 connections
Weight (kg)	3.9
Temperature	
Operating (Qualification)	+4°C to +55°C
Non-Operating (Qualification)	-20°C to +60°C
Service Life	
Storage	7 years
Flight	15 years
Mounting	Pedestal mounting
Heritage	Delivered for CERES, Myriade Evolution, NEOSAT

PEPT-590


H
B
A
X
Upper Hemisphere
Lower Hemisphere
COM Empty Tank
COM Filled Tank
Ø585.4 ±1
311.9 ±1
623 ±1
(750.6)
12 min.
7 min.
1280
550
600
6x M6x1-6H
TRP
X: -260
Y: 138
Xsat
Zsat
Ysat
Y
Z
2 x Ø49.95 ±0.05
2 x Ø28 ±0.2
2 x 32.8 ±1
2 x 63.8 ±0.5
2x M12x1.75-6g
6 x M6x1-6H
12 x 9 min.
12 x 12 max.
DETAIL A
SCALE 1 : 1
2 x Ø6.4 ±0.02
2 x Ø5.58 ±0.02
2 x R0.02max.
2 x 6 ±1
DETAIL B
SCALE 2 : 1
2 x Ø38
12 x 60°
VIEW H
SCALE 1 : 1

PEPT-590

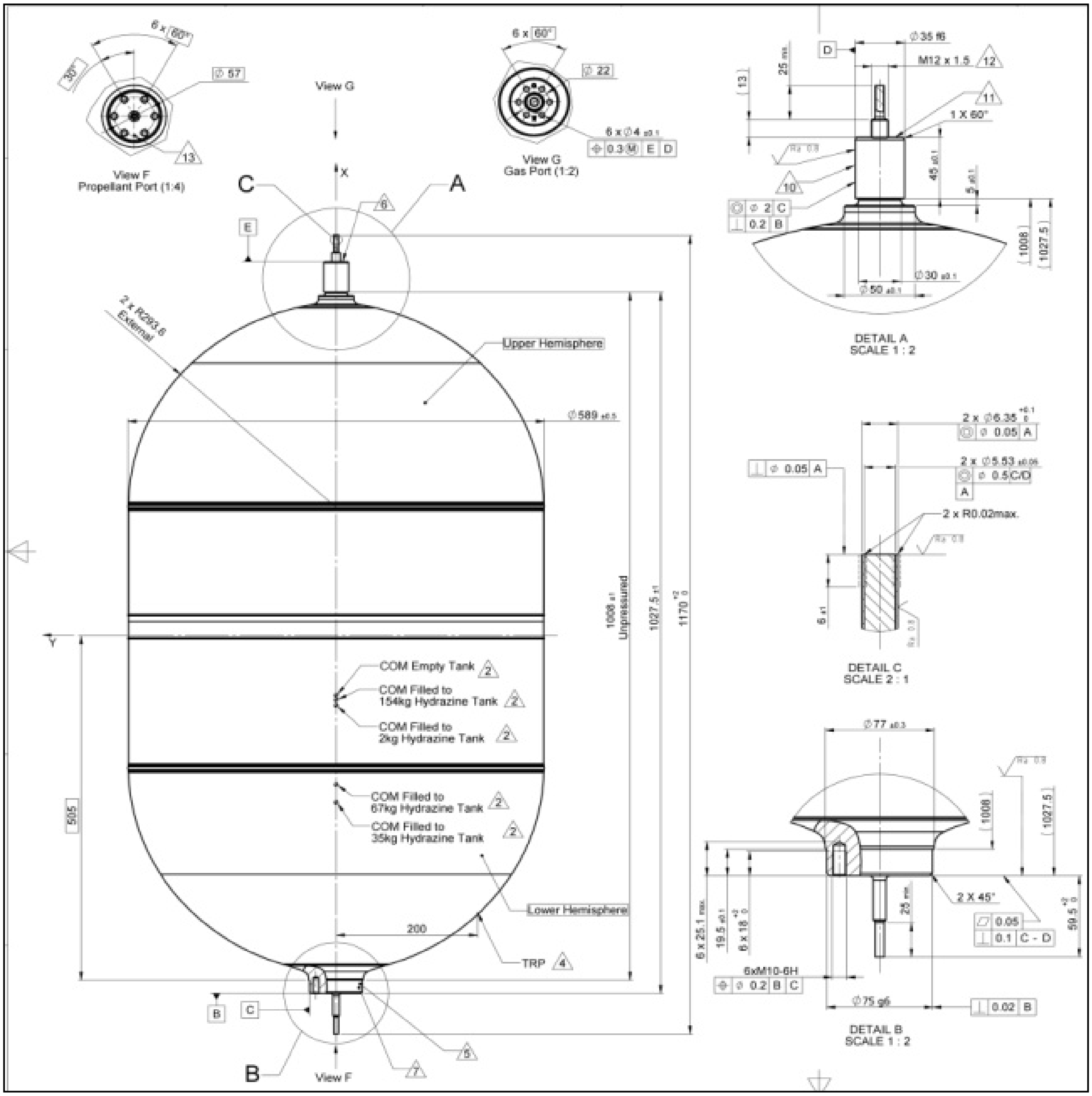
RAFAEL
SMART AND TO THE POINT

Propellant Tanks — PART C

PEPT-590 Main Characteristics

Configuration	Spherical, 586 mm OD
Fluid Media Compatibility	Hydrazine, IPA, distilled water, GN_2, GHe
Pressurant	GN_2, GHe
Minimal Net Volume:	102.5 liter
Propellant Nominal Capacity	75 kg
Liquid Volumetric Expulsion	> 99.1 %
Pressure	
Operating	24.6 to 5.5 bar
Proof	36.9 bar
Burst	49.2 bar
Leakage	
Internal Leakage	$<5.6 \times 10^{-3}$ Scc/s (GHe)
External Leakage	$<1.0 \times 10^{-6}$ Scc/s (GHe) at 24.6 bar
Material	
Tank Material	Ti-6Al-4V
Diaphragm Material	EPN-40: EPDM type silica-free rubber
Ports	ø 1/4" tube weldable connections for both gas and hydrazine ports, made of Ti-6Al-4V
Weight	7.5 kg
Temperature	
Operating (Qualification)	4°C to 60°C
Non-Operating (Qualification)	-20°C to 60°C
Service Life	
Storage	7 years
Flight	15 years
Mounting	Polar mounting
Heritage	Designed and qualified for Galileo IOV, flight heritage with IXV, delivered for Exomars 2020, PRISMA

PEPT-590GB


View F
Propellant Port (1:4)
View G
Gas Port (1:2)
Upper Hemisphere
Lower Hemisphere
COM Empty Tank
COM Filled to
154kg Hydrazine Tank
COM Filled to
2kg Hydrazine Tank
COM Filled to
67kg Hydrazine Tank
COM Filled to
35kg Hydrazine Tank
TRP
1008 Unpressured
DETAIL A
SCALE 1 : 2
DETAIL C
SCALE 2 : 1
DETAIL B
SCALE 1 : 2

PEPT-590GB

PEPT-590GB Main Characteristics

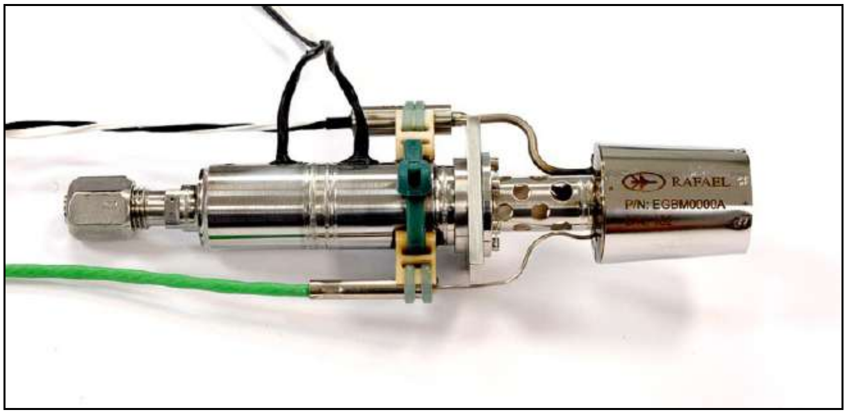
Configuration	Cylindrically extended hemispheres, nominal ∅587 mm x 1,170 mm length
Fluid Media Compatibility	Hydrazine, IPA, distilled water, GN_2, GHe
Pressurizing Media	GN_2, GHe
Nominal Volume	204 liters
Propellant Nominal Capacity	154 kg @ 4: 1 blow-down ratio
Liquid Volumetric Expulsion	> 99%
Pressure	
Operating	27.4 to 5.5 bar
Proof	41.1 bar
Burst	54.8 bar (actual rupture at 72 bar)
Leakage	
Internal Leakage	$<1\times10^{-2}$ Scc/s (GHe)
External Leakage	$<1\times10^{-6}$ Scc/s (GHe) at 27.4 bar
Material	
Tank	Ti-6Al-4V
Diaphragm	EPN-40 (silica free)
Ports	ø 1/4” weldable connections for both gas and hydrazine ports
Weight	17.5 kg
Temperature	
Operating (Qualification)	4°C to 50°C
Non-Operating (Qualification)	-20°C to 60°C
Service Life	
Storage	7 years
Flight	15 years
Mounting	Polar mounting
Heritage	Designed and qualified for Globalstar-2, flight heritage with GB2, O3B and Sentinel-1 satellites in orbit, delivered for COSMO SG

Thrusters

- **Satellite** Thrusters - Chapter D1

- **Launcher** Thrusters - Chapter D2

1N Thruster

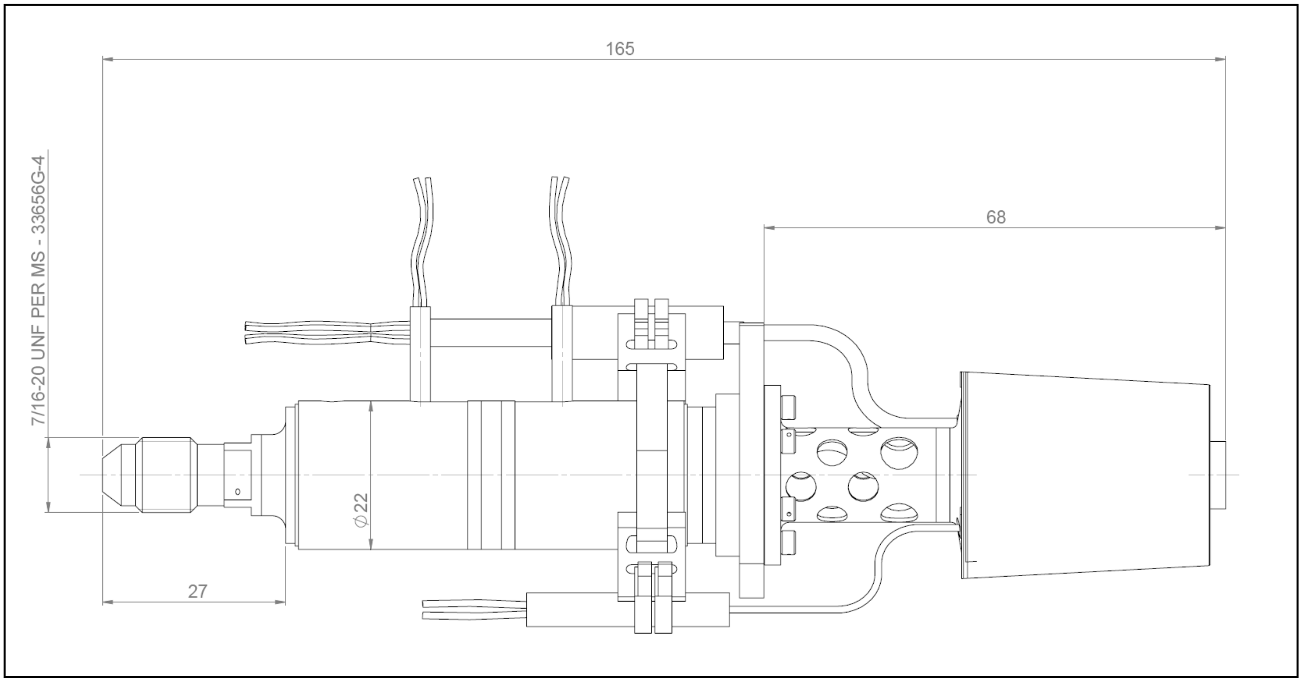


General Description

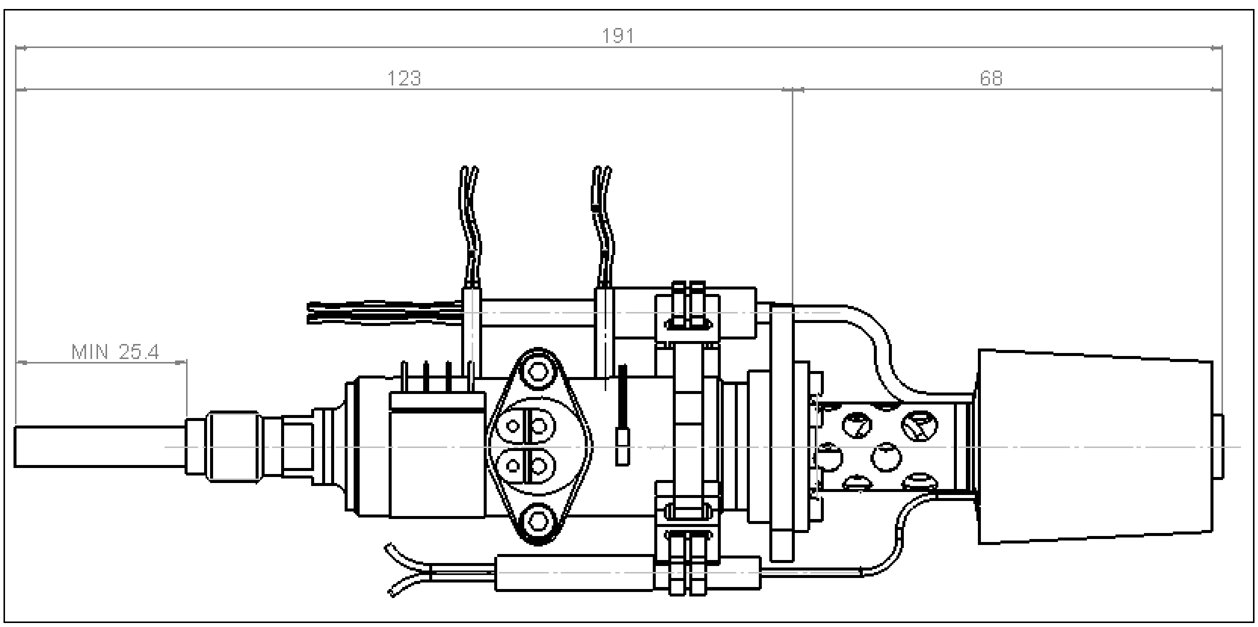
The 1N hydrazine thruster generates the required thrust for maneuvering the satellite by means of a hot gas jet created by hydrazine decomposition and expansion through the exit nozzle. The thruster was designed and qualified for the OFEQ program.

The Rafael 1N thruster was chosen for the following programs: Globalstar-2 (by TAS-F), O3B constellation (by TAS-F), NEOSAT Space bus (by TAS-UK), Cosmo SG (by TAS-I), Prisma (OHB-I) and for ESA programs: Galileo IOV (by EADS-ST), Sentinel-1 A, B, C & D (by TAS-I), Koreasat (by TAS-I) and Sabia-Mar (by CONAE).

The 1N thruster is governed by a solenoid-operated, dual-coil, dual-seat normally-closed Flow Control Valve (FCV). The Normally-closed position is maintained by springs for both seats. The FCV is equipped with an integral, 15 micron absolute filter , installed at the valve inlet.



1N Thruster (threaded connector inlet)



1N Thruster (tube inlet FCV with thermal components)

Satellite Thruster PART D1

The normally-closed FCV is operated by its solenoid, opened when energized and shut-off by electric switch-off. The valve is an all-welded construction.

The FCV consists of the following main parts: inlet port (filter included), valve body; coils (2); springs (2); seats (2); plungers (2) and a mounting flange.

The all-welded FCV and the Thrust Chamber Assembly (TCA) are assembled together through a perforated, Hayness-alloy tubular element, which serves as a thermal barrier between the TCA and the FCV. The thermal barrier controls heat conduction from the TCA to the FCV, throughout thruster operation and the heat soak-back period. A metallic seal provides the leak tightness between the FCV and the TCA.

The TCA incorporates a bell-shaped nozzle, with an expansion ratio of ε=130. It is welded to the decomposition chamber and provides the required thrust.

The FCV has been developed and qualified by Rafael, as an integral part of its policy to develop an in-house capacity for components and processes.

Rafael 's thrusters are free of any ITAR restrictions.

The thruster is equipped with an electric catalyst bed heater (CBH), with two resistance coils, providing the initial thermal condition required for long duration and repeatable operation. The pre-heating time is required for reliable start of the thruster. The recommended pre-heating temperature is 180°C. The elapsed time to reach this temperature depends on the thruster's initial temperature. A typical time for pre-heating from +25°C is about 20 minutes.

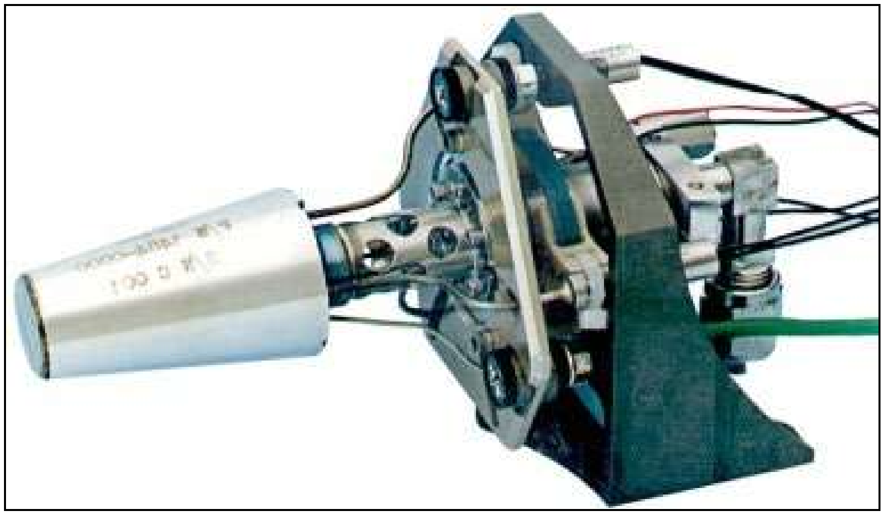
Thruster inlet connection to the system tubing is through an MS 33656-4 threaded connector, complying with the requirement for a screwed connection.
Alternatively, the thruster may be supplied with 1/4" or 3/8" welded inlet tube, according to customer preference.

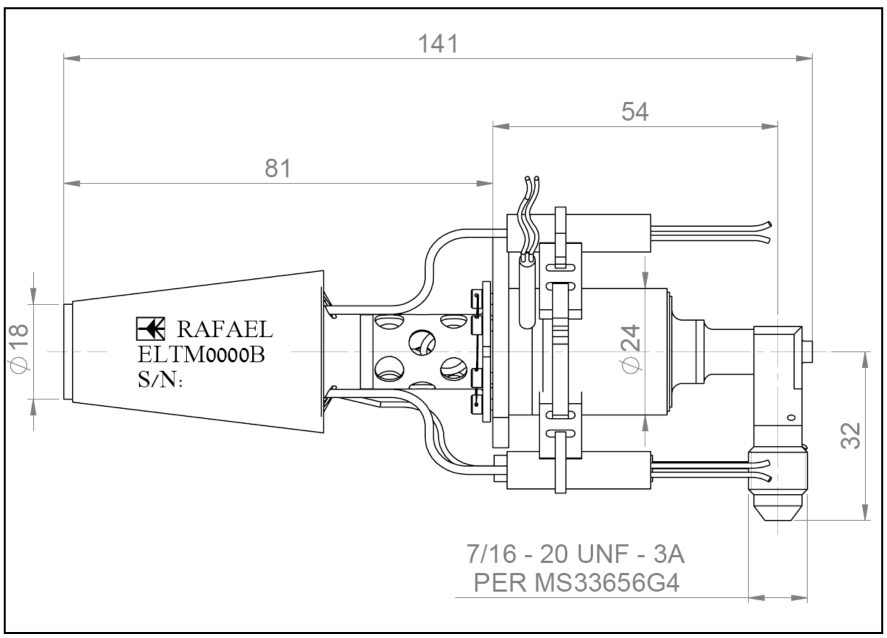
There is no limitation on FCV heaters and thermistors bonding on free areas on the external envelope of the FCV.

1N Thruster Main Characteristics

Parameter	Characteristics	
Propellant	Hydrazine (N2H4)	
Feed Pressure (bar abs)	Type 1	Type 2
	24.5 to 9	24.5 to 5.5
Thrust (BOL), Steady State (N)	1.3 ÷ 1.4	1.0 ÷ 1.1
Thrust (EOL), Steady State (N)	> 0.2	
SSF Specific Impulse (sec)	>214 @ 22 bar	
	>205 @ 5.5 bar	
Minimum Impulse Bit (N-s)	0.008 @ 5.5 bar and D/C 0.02 sec/1 sec	
Nominal Duty Cycle	0.1 sec / 1 sec	
Response Time (Hot Pulse)		
Rise Time (ms)	< 200 @ nominal duty cycle	
Decay Time (ms)	< 300 @ nominal duty cycle	
Total Delivered Impulse (N-s)	Type 1	Type 2
	100,000	60,000
Total Number of Pulses	Type 1	Type 2
	100,000	58,000
Leakage		
Internal Leakage (Scc/s GHe):	< $1.0x10^{-5}$ @ 5.5 bar and 24.5	
External Leakage (Scc/s GHe):	< $1.0x10^{-6}$ @ 24.5	
Temperature	Operating: +5°C to 90°C Non Operating: -10°C to 95°C	
Flow Control	FCV – dual-coil, dual seat, NC solenoid valve	
FCV Operating Voltage (Vdc)	23 to 36	
FCV Power (W)	9.2 @ 28 Vdc	
Heater – Dual Element		
Heater Operating Voltage (Vdc)	23 to 36	
Heater Resistance (ohms)	257 for each element	
Nozzle Expansion Ratio	130	
Total Life (Storage and Flight)	15 years	
Inlet Filtration	15 micron absolute	
Inlet Interface	MS 33656-4 or welded tube (1/4" or 3/8")	
Weight (gr.)	≤ 310 (1000 mm lead wire length)	
Heritage	Qualified for OFEK, Globalstar-2, O3B, Neosat and GALILEO IOV. Flight heritage with Globalstar-2, O3B, Venus, GALILEO-IOV, Sentinel-1, Gokturk PS2, COSMO SG, Neosat SB and PRISMA.	

5N Thruster



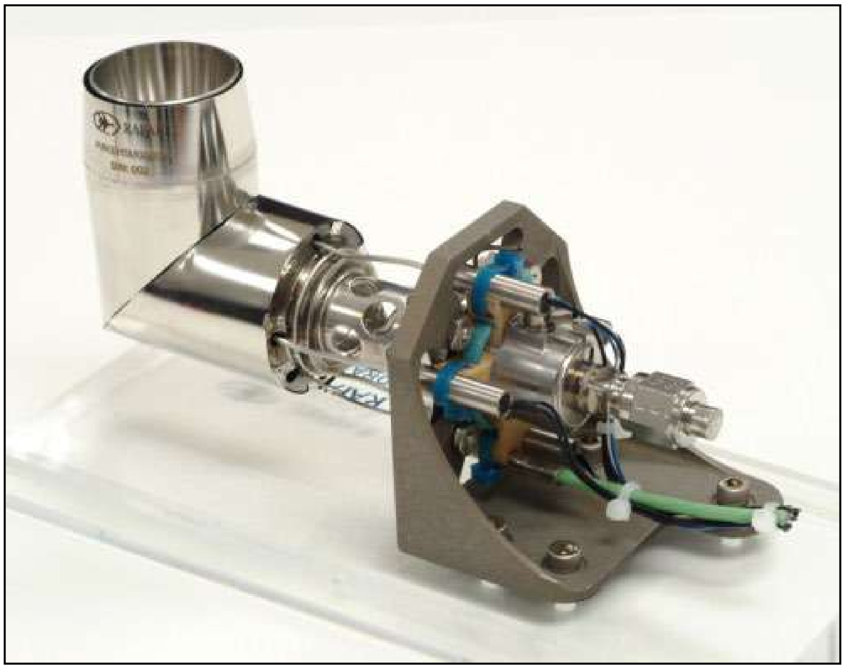


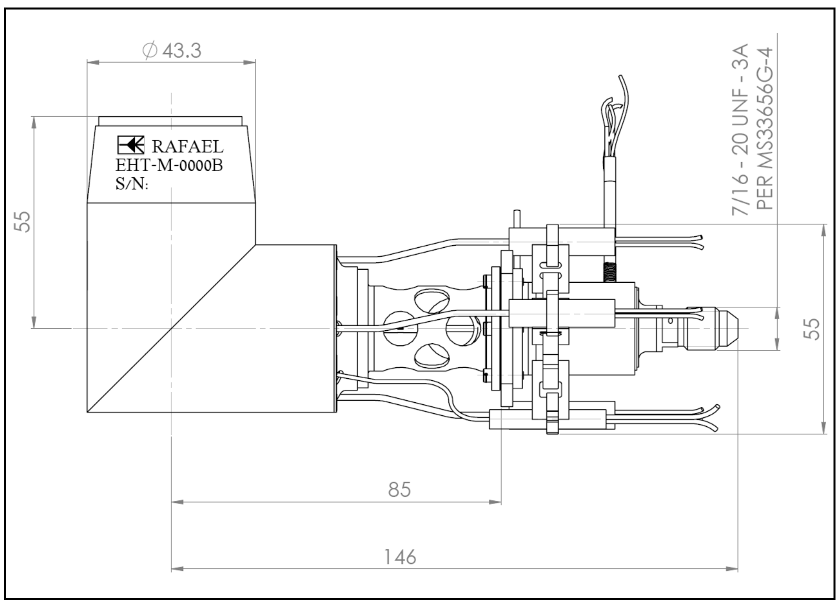
5N Thruster

5N Thruster Main Characteristics

Parameter	Characteristics
Propellant	Hydrazine (N_2H_4)
Feed Pressure (bar abs)	24 to 5.5 (nominal), tested down to 4.5
Thrust, Steady State (N)	6.1 @ 22 bar to 1.8 @ 5.5 bar
SSF Specific Impulse (sec)	>220 @ 22 bar
	>210 @ 5.5 bar
Minimum Impulse Bit (N-s)	<0.25 @ 5.5 bar & 0.1 sec / 1 sec <0.012 @ 5.5 bar & 0.06 sec / 1000 sec
Nominal Duty Cycle	0.1 sec / 1 sec
Response Time (Hot Pulse)	
Rise Time(ms)	< 65 @ nominal duty cycle & 22 bar
Decay Time (ms)	<100 @ nominal duty cycle & 22 bar
Total Delivered Impulse (N-s)	74,000
Total Number of Pulses	42,000
Leakage	
Internal Leakage (Scc/s GHe)	$<1.0x10^{-4}$ @ 3.5 and 24 bar
External Leakage (Scc/s GHe)	$<2.6x10^{-4}$ @ 24 bar
Temperature	
Operating Temperature	+4°C to 90°C
Non Operating Temperature	-10°C to 90°C
Flow Control	FCV - single-coil, dual-seat, NC solenoid valve
FCV Operating Voltage (Vdc)	23 to 36
FCV Power (W)	9.2 @ 28 Vdc
Heaters - 3× Single Heaters	
Heater Operating Voltage (VDC)	24 to 32
Heater Resistance (ohms)	260 per each heater
Nozzle Expansion Ratio	50
Total Life (Storage and Flight)	15 years
Inlet Filtration	15 micron absolute
Inlet Interface	MS 33656-4 or welded tube (1/4" or 3/8")
Weight (gr.)	≤ 310 (2000 mm lead wires length)
Heritage	Flight heritage with OFEQ, EROS, SAOCOM and TECSAR programs

25N Thruster





25N Thruster

25N Thruster Main Characteristics

Parameter	Characteristics
Propellant	Hydrazine (N_2H_4)
Feed Pressure (bar abs.)	22 to 5.5
Thrust, Steady State (N)	28 to 9.5
SSF Specific Impulse (sec)	> 220 @ 22 bar
	> 205 @ 5.5 bar
Minimum Impulse Bit (N-s)	0.3
Nominal Duty Cycle	0.24 sec / 1 sec
Response Time (Hot Pulse)	
Rise Time (ms)	65 @ nominal duty cycle & 22 bar
Decay Time (ms)	200 @ nominal duty cycle & 22 bar
Total Delivered Impulse (N-s)	100,000 (<5%Isp degradation)
Total Number of Pulses:	12,000
Leakage	
Internal Leakage (Scc/s GHe):	$<1.0\times10^{-4}$ @ 3.5 & 24
External Leakage (Scc/s GHe):	$<1.0\times10^{-6}$ @ 24
Temperature	
Operating Temperature	+4°C to 90°C
Non-Operating Temperature	-10°C to 90°C
Flow Control	FCV - single-coil, dual-seat, NC solenoid valve
FCV Operating Voltage (Vdc)	23 to 36
FCV Power (W)	15 @ 28 Vdc
Heaters – 4× Single Heaters	
Heater Operating Voltage (Vdc)	24 to 32
Heater Resistance (ohms)	260 per each heater
Nozzle Expansion Ratio	60
Total Life (Storage & Flight)	15 years
Inlet Filtration	15 micron absolute
Inlet Interface	MS 33656-4 or welded tube (1/4" or 3/8")
Weight (gr.)	≤ 530 (1000 mm lead wires length)
Heritage	Flight heritage with OFEQ and EROS programs

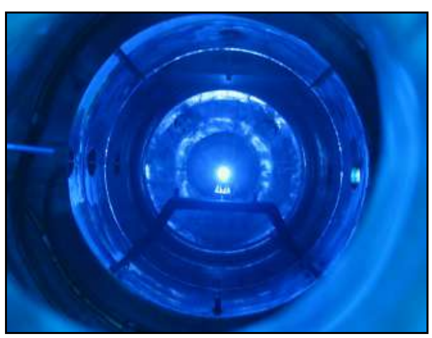
IHET-300 Thruster

The heart of the Venμs Electric Propulsion System (EPS) is the Israeli Hall-Effect Thruster (IHET), code named IHET-300. It operates on Xenon, which is ionized by electrons emitted from the cathode and accelerated as plasma using a high electric field.

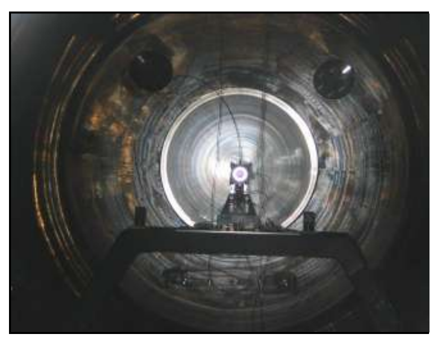
This thruster is ideal for use onboard small and micro satellites, operating nominally on a mere 300W anode power. However, its useful range of operation is between 250 to 600W. Thus, it may utilize the instantaneous available power from the satellite.

IHET-300 Main Characteristics

Characteristics	Parameter
Thrust (@300W)	> 14.3 mN
Specific impulse (@ 300W)	> 1200 sec
Nominal anodic power	300W
Power operation range	250W to 600W
Total Impulse	>135 kN
Operating life	> 1000 hours
Number of operations cycles	> 2000
Mass	1.6 kg
Dimensions	170x120x90 mm
Heritage	Flight heritage – Venus Program



Thruster during Test Firing in Firing chamber



Thruster installed in Firing chamber

R-200 Thruster

The R-200 is a low power Hall thruster designed to operate in the 100-300 W discharge power range, suitable for low to medium mass satellite platforms (<500 kg). The thruster produces thrust levels of 5-14 mN at specific impulse of 800-1,300 sec, depending on the selected operation power. It completed full qualification, including shock and vibration and full lifetime tests.

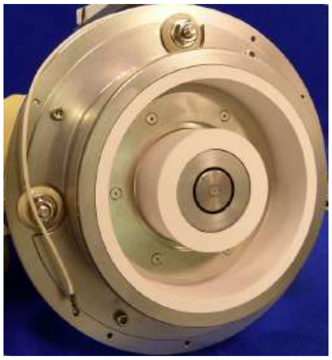
To overcome the low mass utilization efficiency issues associated with low power Hall thrusters the R-200 Hall thruster includes a non-conventional configuration that consists of co-axial anodes and an elongated discharge channel.

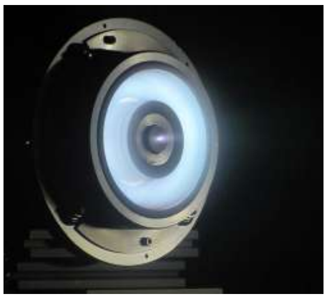
The R-200 Hall thruster underwent a development program that included proof-of-concept tests, experimental and numerical validation of physical mechanisms, wall material selection, performance testing, thruster engineering model structural, thermal and magnetic simulations followed by an engineering model production as well as full performance mapping. Following these development phases a Qualification Model (QM) of the thruster was produced and successfully tested in a steady state performance characterization test, ignition tests, shock and vibration test and a 75 kN-sec (1,500-hrs) endurance test.

The thruster makes use of a low current heaterless hollow cathode; therefore increasing the thruster's lifetime, readiness time and reliability while eliminating the need for a power-consuming heater power supply, in comparison with traditional Hall thrusters.

R-200 Main Characteristics

Characteristics	Parameter
Power	100-300 W
Thrust (Xe)	5-14 mN
Specific impulse (Xe)	800-1300 sec
Propellant	Xe, Kr
Total Impulse	> 200 kNs
Mass	2 kg





R-800 Thruster

The R-800 is a low power Hall thruster designed to operate in the 450-900 W discharge power range suitable for low to medium mass satellite platforms (<1,000 kg). The thruster produces thrust levels of 23-53 mN at specific impulse of 1,300-1,550 sec. The R-800 has low mass and low volume footprint, thanks to its center-mounted cathode and permanent magnet configuration.

The thruster has a conventional Hall thruster configuration with the gas distributer serving also as the anode. It also benefits from a unique set of materials and structure design that make it relatively light weight. Additionally, the R-800 Hall thruster consists of permanent magnets and a center-mounted cathode, making it energy efficient with a low volume footprint.

The thruster makes use of a low current heaterless hollow cathode; therefore increasing the thruster's lifetime, readiness time and reliability while eliminating the need for a power-consuming heater power supply, in comparison with traditional Hall thrusters.

Rafael provides fully integrated propulsion systems that include the thruster unit, the power processing unit, system operation controller and the propellant management assembly.

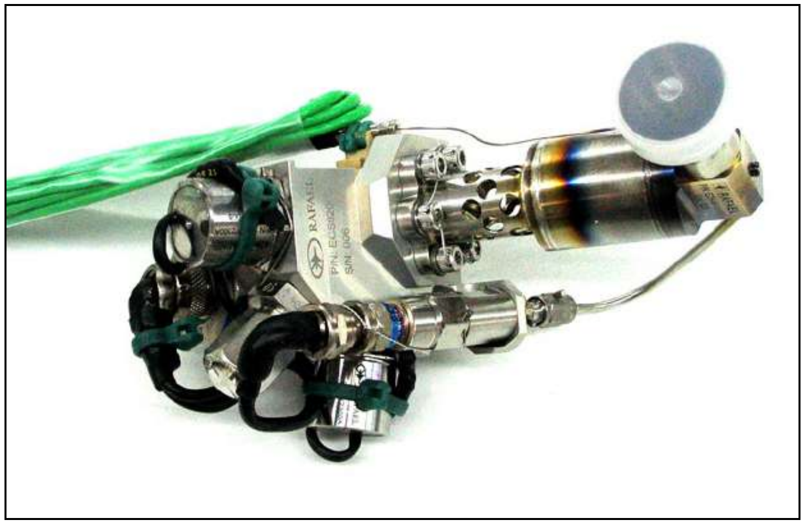
R-800 Main Characteristics

Characteristics	Parameter
Power	450-900 W
Thrust (Xe)	24-53 mN
Specific impulse (Xe)	1,300-1,550 sec
Propellant	Xe, Kr
Total Impulse	> 750 kNs
Mass	1.5 kg

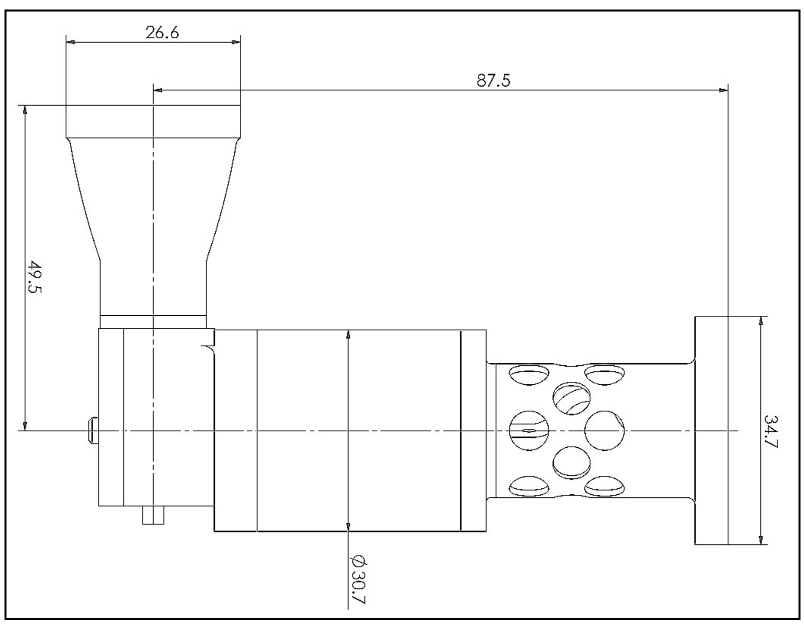
Thrusters

Launcher Thrusters

25N Thruster



25N Thruster integrated in the Roll Attitude control system (RACS) cluster including valves, pressure transducer and electronic driver

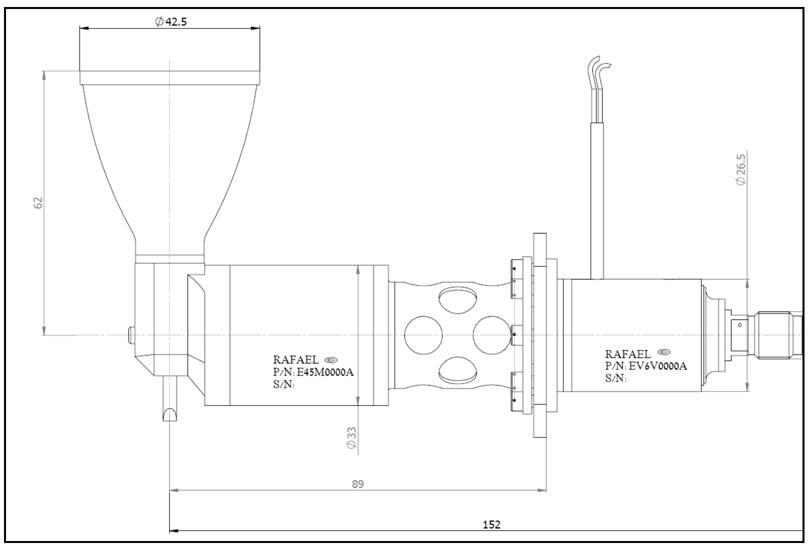


25 N Thruster

25N Thruster Main Characteristics

Characteristics	Parameter
Propellant	Hydrazine (N_2H_4)
Feed Pressure (bar abs.)	26.2
Thrust, Steady State (N)	24
SSF Specific Impulse (sec)	>220 @ 24 bar
	>210 @ 6 bar
Minimum Impulse Bit (N-s)	1.5
Weight (gr.)	310
Heritage	Israeli satellite launcher

45N Thruster



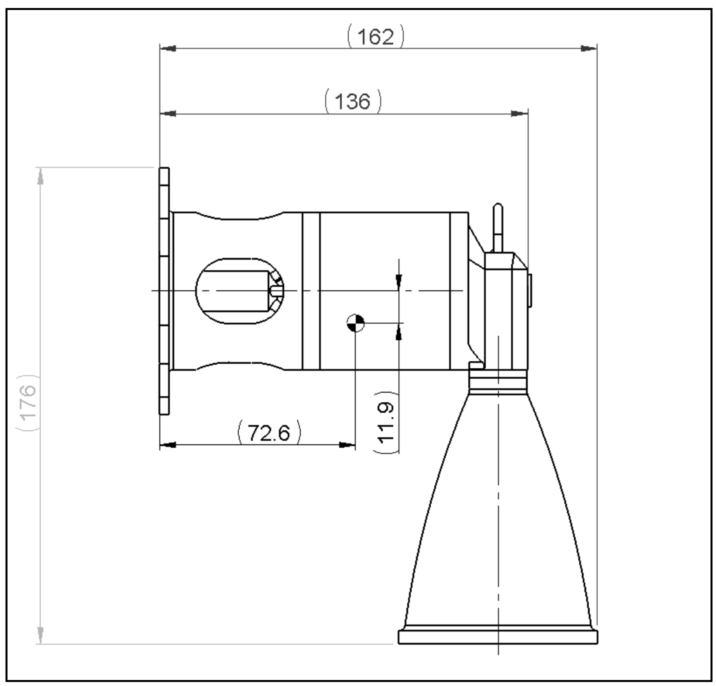
45 N Thruster

45N Thruster Main Characteristics

Propellant	Hydrazine (N_2H_4)
Feed Pressure (bar abs.)	24 to 6
Thrust, Steady State (N)	45 to 16
SSF Specific Impulse (sec)	>208 @ 24 bar
	>190 @ 6 bar
Total Impulse (N-s)	
SSF	60,000
PMF	15,000
Impulse Bit (N-s)	5.3 @ 24 bar & 100 msec. ON
	2.3 @ 6 bar & 100 msec. ON
Response Time (Hot Pulse)	
Rise Time (ms) Decay Time (ms)	100 @ 24 bar
	200 @ 24 bar
Leakage	
External Leakage (Scc/s GHe)	<1 x 10^{-4} @ 3.5 & 24 bar
External Leakage (Scc/s GHe)	<2.7 x 10^{-4} @ 24 bar
Flow Control	FCV - single-coil, single-seat, N.C. solenoid valve
FCV Operating Voltage (Vdc)	24 - 32
FCV Power (Watt)	17@ 28 VDV & 20°C
Inlet Filtration	15 microns absolute
Inlet Interface	MS 33656-4
Nozzle Expansion Ratio	50
Weight (gr.)	500 (500 mm lead wires length)
Heritage	Space Qualified

200N Thruster

Characteristics	Parameter
Propellant	Hydrazine (N_2H_4)
Feed Pressure (bar abs.)	31 (nominal), down to 8
Thrust, Steady State (N)	200±5%
SSF Specific Impulse (sec)	>220
QSS MIB (N-s)	< 17.5 at D/C 0.08/2
Rise Time 90% (ms)	<150
Decay Time 10% (ms)	< 250
Flow Control	FCV - single-coil, single-seat, NC solenoid valve
Nozzle Expansion Ratio	50
Weight (gr.)	≤ 1,250
Heritage	Israeli satellite launcher



200 N Thruster

200N Thrusters integrated in the RACS cluster containing valves, pressure transducer and electronic driver

Propulsion System Valves

Rafael Propulsion System Valves

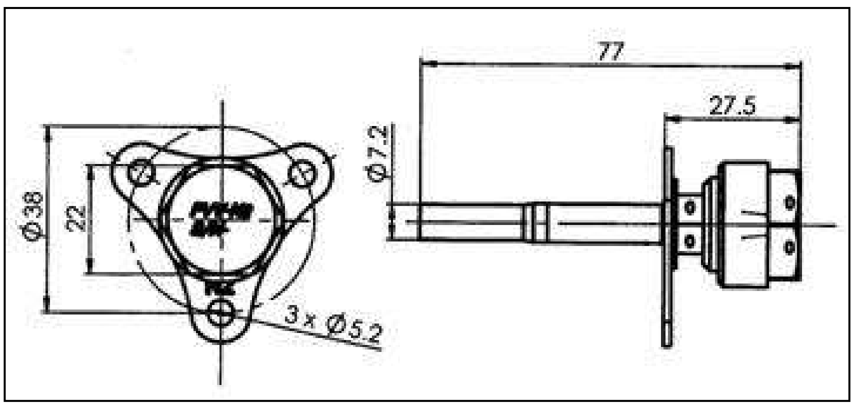
FDV/FVV – Service valves General Description

FVV

Each propulsion system contains Fill and Drain Valve (FDV) which is used for controlled loading or draining of propellant, as well as Fill and Vent Valve (FVV) which is used for pressurizing or venting of Nitrogen. These valves have no active function after launch.

Although the general design is identical for the FDV and FVV, they differ by their interface thread sizes. This provides non-interchangeable connections for propellant and pressure usage. Connection to the loading, draining and pressurizing Ground Support Equipment (GSE) is executed through the GSE part which opens and closes the desired valve and is disconnected prior to launch.

Redundant sealing is provided by two seals in series; a primary metal-to-metal seal is tightly secured after propellant or pressurant loading by means of a threaded retainer, the secondary sealing is implemented by a hydrazine resistant O-ring gasket, located within the external cap, a Ti welded interface connection is provided at the 1/4" diameter valve outlet.

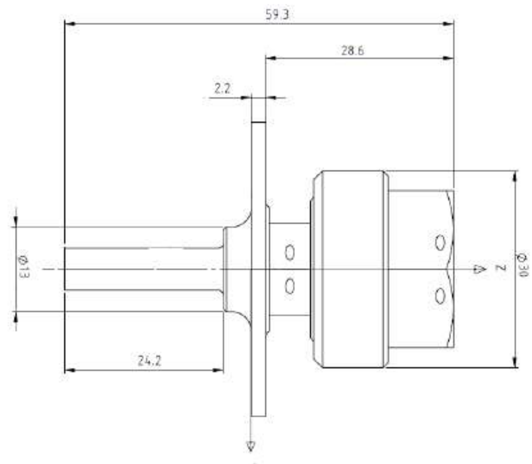


FDV/FVV

Three barriers valve

Three Barriers FDV

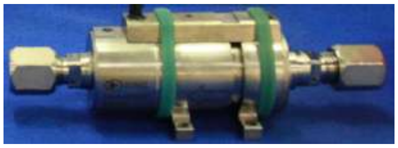
Rafael P/N EFDV6000A, is a fully-qualified updated 3-barriers version of the FDV that serves for the filling of propellant into the propulsion system; it also serves for draining the system of its propellant, if necessary.



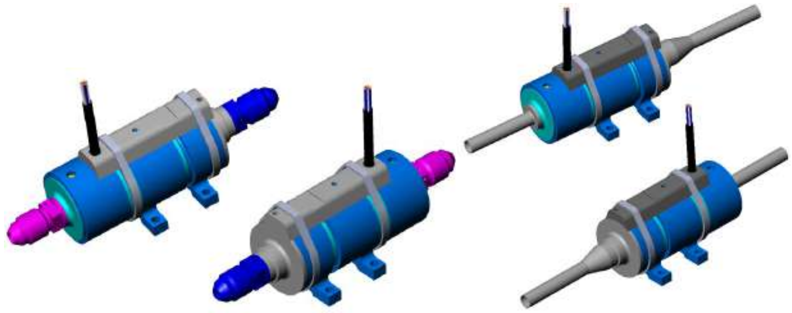
Three barriers FDV

FDV/FVV Main Characteristics

Parameter	Characteristic
Fluid media compatibility	Hydrazine, IPA, distilled water, GN_2, GHe
Operating pressure (bar)	0 to 24 (2 barriers' FDV/FVV) 0 to 30 (3 barriers' FDV)
Proof pressure (bar)	36 (2 barriers' FDV/FVV) 45 (3 barriers' FDV)
Burst pressure (bar)	112
External leakage (Scc/s GHe)	$<1x10^{-6}$ at 24 bar (2 barriers' FDV/FVV) $<1x10^{-6}$ at 30 bar (3 barriers' FDV/FVV)
Close-open-close cycles	>100 per each barrier
Body material	Titanium (Ti)
Weight (g)	60 for FDV/FVV, 80 for 3 barriers' FDV
Life	15 years
Heritage:	OFEQ, PRISMA (OHB-I)



Latch Valve



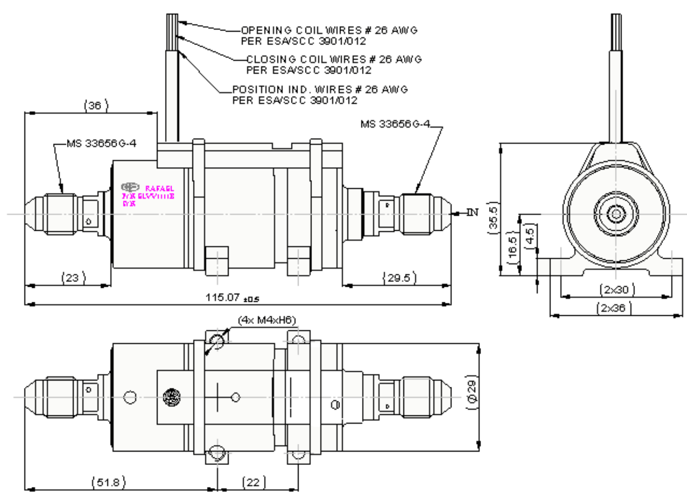
LV General Description

The solenoid operated latching valve (LV) is dual-coil, single-seat magnetically latched. A momentary electric input signal is required to change the position of the plunger; the appropriate coil is pulse-energized, and switches the plunger from OPEN to CLOSED position, or vice-versa.

Once the LV has changed its position, a permanent magnet provides the magnetic latching force necessary to maintain it in its last selected position, and no further energizing is required.

The valve employs a 15-micron absolute integrated filter.

The LV is equipped with a reed-switch (magnetic type), which operates as a limit switch (connect/disconnect capability), providing an indication of the valve position.



Latch Valve

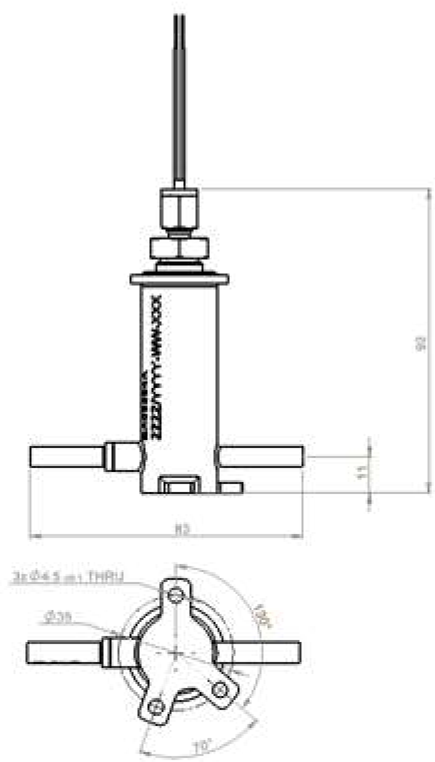
LV Main Characteristics

Parameter	Characteristic Data
Valve Type	Magnetic latching, solenoid operated
Fluid Media Compatibility	Hydrazine, IPA, distilled water, GN_2, GHe
Pressure	
Operating (bar)	0 to 24
Proof (bar)	36
Burst (bar)	96
Pressure Drop (bar)	<1 @ 20 gr/sec hydrazine
Back Pressure Relief (Δbar)	<14
Electrical	
Operating Voltage (Vdc)	24 to 32
Power (W)	25 @ 28 Vdc for each coil
Minimum Voltage Actuation Time (sec)	$\geq$1
Operating Response Time (ms)	< 50 @ 28 Vdc and 24 bar
Pull In Voltage (Vdc)	< 20 @ 24 bar
Insulation Resistance (MΩ)	100 @ 100 Vdc
Dielectric Resistance (MA)	2 @ 500 Vac & 50/60 Hz
Leakage	
Internal Leakage Scc/s (GHe)	<1 $x10^{-4}$ @ 3.5 and 22 bar
External Leakage Scc/s (GHe)	<1 $x10^{-6}$ @ 36 bar
Temperature	
Operating Temperature	+5°C to 80°C
Non-Operating Temperature	-10°C to 90°C
Life	
Storage	7 years
Flight	8 years
Cycle	>20,000
Built-In Position Indication	Magnetic position sensor
Built-In Filter:	15 microns abs.
Inlet & Outlet Interface:	MS 33656G-4 or 0.25" tubes
Weight (gr.)	< 370
Heritage	OFEQ and other foreign customers

Shape Memory Alloy Valve - SMAV

SMAV General Description

Shape Memory Alloy Valve (SMAV) is an inert solution for one-shot device based on smart materials. SMA is well known for its chemical and physical durability. SMAV contains a single-core cartridge heater that can be tested during pre-flight without damaging SMAV's functionality. Hence, this valve has superior reliability. SMAV is a hermetic device since its inlet is sealed with a nipple which is sheared by the SMA actuator. SMAV exhibits excellent internal and external leakage. Inlet and outlet tubes are 1/4" Titanium.



SMA Valve

SMAV Main Characteristics

Parameter	Characteristic Data
Valve Type	NC, SMA operated
Fluid Media Compatibility	Xe, Kr, Ar, GN_2, GHe, De-Ionized Water, IPA
Pressure and Mass Flow	
Operating (bar)	0 to 330
Proof (bar)	495
Burst (bar)	1320
Pressure Drop (bar)	negligible @ max pressure
Flow (gr/min)	2 @ 186 bar
Electrical	
Operating Voltage (Vdc)	28±1
Power (Watt)	12W @ 28 Vdc
Operating Response Time (sec)	<120 @ 28 Vdc & 330 bar
Insulation Resistance (MΩ)	100Mohm with 100 Vdc
Dielectric Resistance (mA)	2 @ 500 Vac & 50/60 Hz
Leakage	
Internal Leakage Scc/s (GHe)	$<1 \times 10^{-6}$ @ 330 bar
External Leakage Scc/s (GHe)	$<1 \times 10^{-6}$ @ 330 bar
Temperature	
Operating Temperature	+12°C to 50°C
Non-Operating Temperature	-20°C to 65°C
Life	
Storage	7 years
Pre-Activation (Pressurized)	4 years
Flight (Post-Activation)	15 years
Cycle	1
Inlet & Outlet Interface	MS 33656G-4 or 0.25" tubes
Weight (gr.)	160

Space Production Capabilities

Clean Rooms

Components and subsystem assembly and integration are carried out in special clean room facilities, complying with US Federal Std. 209B, ranging from Class 100,000 to Class 100.

Parts, components and subassemblies are cleaned to the highest levels using special equipment (ultra-sonic, flushing benches) and checked for level of cleanliness using computerized particle counters (gas and liquid) and UV light. Hydraulic and pneumatic flow benches, equipped with special tools for flow control adjustment, flow calibration and hydraulic response time measurements, have been installed in the clean room.

Orbital welding is used for tubing manifolds manufacturing and propulsion system integration in the clean room.

A new clean room, completed in 2010, houses the propulsion modules production including the components production.

The new clean room includes assembly, integration and testing (AIT) sections from the components' level through the sub-assemblies level and four stations of propulsion system AIT.

Rafael 1,000 m² Clean Room Site

Vacuum/Spin Test Facility

Hydrazine Thruster Test Firing

Hydrazine thrusters hot-firing tests are carried out at Rafael facilities, which include open air test stands as well as four vacuum chambers delivering 10^{-3} torr. One of these includes a spin table for functional tests under actual spin conditions. In these facilities thruster activation, data acquisition, reduction and analysis are highly automated and remotely operated using video and computer equipment & techniques. Methods have been developed to cater for special requirements, such as accurate measurement of thrust and impulse, ranging from high to very low values (corresponding to a wide range of duty-cycles), thermal measurements and flow visualization in vacuum of transparent thruster exhaust gases by RF glow discharge effect, etc.

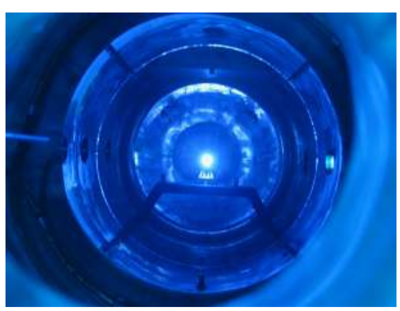
Vacuum chambers for space simulation at Rafael Test Firing Facility

Electric Thruster Test Firing

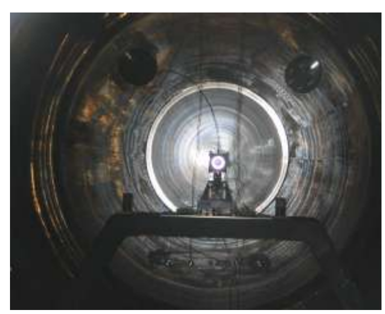
Electric-thrusters hot-firing tests are carried out at Rafael facilities in a vacuum chamber. The chamber is capable of testing a wide range of electric thrusters up to a full propulsion system (2.5 meters diameter). The vacuum chamber may accommodate measurements of thrust, from 5 to 120 mN, while evacuating the residual gases and keeping the vacuum environment of up to $5 \cdot 10^{-7}$ mbar.

The vacuum chamber is continuously monitored by a double set of pressure transducers, a residual gas analyzer and a video recording system.

Electrical Test Firing Chamber



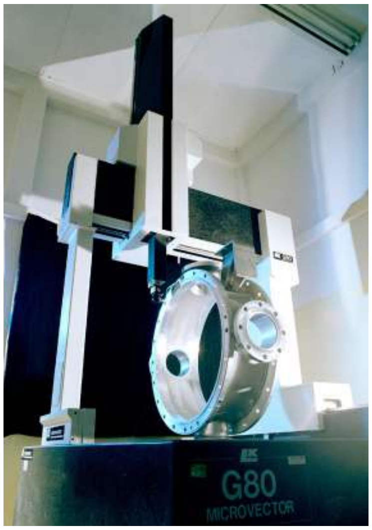
IHET 300 Thruster during Test Firing



IHET 300 Thruster installed inside Test Firing Chamber

Additional small vacuum chambers at Rafael facilities serve for electric propulsion development and tests.

Electrical Development and Test Firing Chambers



Automatic CMM Dimensional Inspection

Testing and Inspection Facilities

The Rafael test and inspection facilities include a wide range of environmental tests (all aspects of dynamic, climatic, thermal, and vacuum) as well as metallurgical, chemical and dimensional inspection and analytic laboratories.

A wide range of non-destructive capabilities, such as X-ray, dye penetrant inspection, ultra-sonic are available for development, qualification, production and acceptance tests.

Propellant Tank mounted on shaker for Vibration Testing

X-ray Device

Production Capabilities PART F

Manufacturing

A wide range of highly qualified manufacturing facilities are available to meet space standards and requirements. These include CAD/CAM; CNC machining; electro-erosion; forming; hydro-spinning and deep hot- and cold-drawing; surface treatment; heat treatment; welding (including EBW, GTAW, GMAW, plasma); brazing; cutting, bending and faring of titanium tubes; rubber and composite materials manufacture.

Rafael's capabilities are complemented by using the existing facilities at SOREQ Nuclear Research Center, for testing of components at various radiation levels and their proof of operation in space conditions.

Diaphragm Material Roll Mill

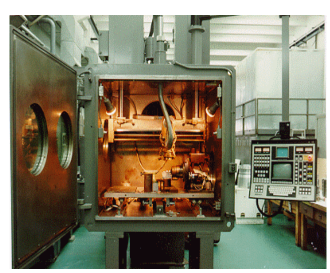
Press

Shear Spinning Device

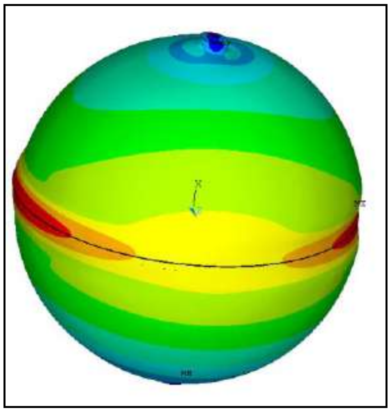
Surface Treatment Facility

Electron Beam Welding

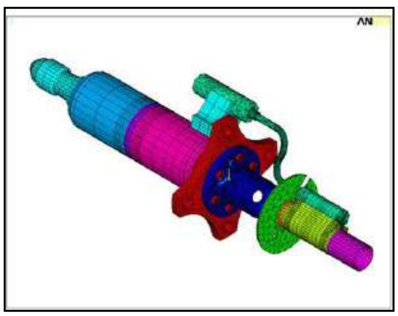
5 Axes CNC Center



Electron Beam Welding



Propellant Tank Modal Analysis



1N Thruster's 3D FE Model

Analytic Resources

Rafael possesses a wide range of expert computational capabilities.

Dynamic and static structural analyses are performed by highly specialized expert groups, using known finite element codes. The capabilities include fracture mechanics and fatigue analysis. The PRODERA real time modal analysis system is used for frequency testing. Various computational fluid dynamics (CFD) and test resources are used for the necessary hydraulic transient (water hammer and sloshing) evaluation.

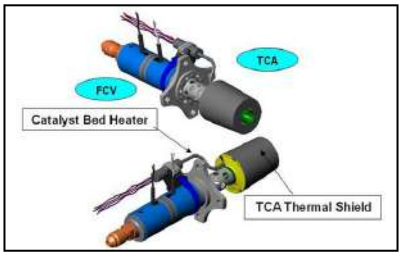
Structural Analysis

The Structural Analysis Group constitutes a center of excellence for structural analysis and structural testing at RAFAEL. The wide range of engineering challenges met over the years is reflected in the group's wealth of collective experience and expertise.

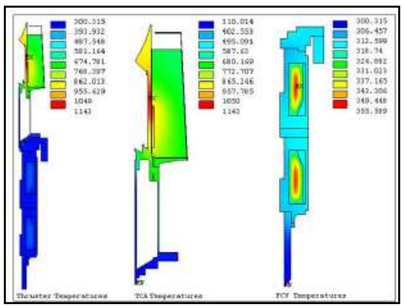
Professional Fields of Activity:

- Finite element methods
- Static and dynamic linear and nonlinear analysis
- Composite materials
- Smart materials
- Viscoelsticity, hyper-elasticity
- Failure analysis
- Fracture mechanics and fatigue
- Aeroelasticity
- Structural testing
- Design of special purpose load transducers
- Real time measurement of flight loads
- Ground vibration testing

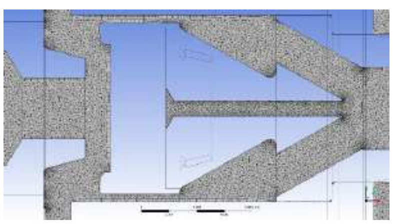
Production Capabilities PART F

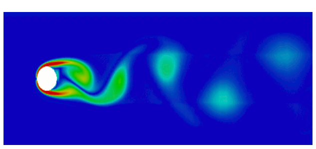


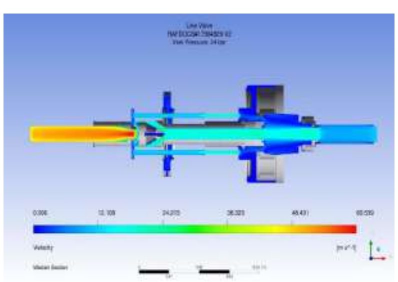
1N Thruster Model View



1N Thruster Thermal Analysis







Valve Flow Analysis

Mechanical Design Tools

3-D CAD software, such as SolidWorks™ is used for layout design of the PS. The CAD models are used for thermal, structural and mass properties analysis.

Heat and Mass Transfer Analysis

The Heat and Mass Transfer Analysis Group is responsible for the thermal design and analysis of most of Rafael's products. It is the largest thermal design group in Israel.

The group activity covers all aspects of thermal design required for the aerospace and military industry including: thermal and fluid flow analysis, development and implementation of thermal solutions, and experimental validation (laboratory and field experiments).

The group uses various commercial and in-house codes for simulations including SINDA/G, PATRAN, SINDARAD and FLUENT. The group also developed codes and subroutines for heat transfer, thermal signature, ablation and aero-heating simulations.

The group's heat transfer laboratory is capable of conducting experimental validation of thermal analysis using a variety of experimental setups to simulate conduction, convection and radiation processes through measurement of temperatures (contact and non-contact methods), heat fluxes and thermal properties (conductivity, diffusivity, specific heat and emissivity using standard and self-developed techniques).

Ground Support Equipment

Ground support equipment (GSE) is used for testing components and systems. A dedicated alignment method assists in the alignment of thrusters in the systems. Propellant, pressurant and test fluid loading, unloading and vacuum leak checks are accomplished by general and custom-made benches and trolleys, all developed and fabricated by Rafael. Leak checks of components, subassemblies and complete systems are carried out using helium mass-spectrometers, and internal dryness is assured using a sensitive hygrometer.

The varied fields of expertise at our disposal enable us to benefit from the wide base of Rafael's infrastructure and at the same time take advantage of the specific hydrazine propulsion technology developed during years of experience.

GSE Propulsion Systems Electrical Tester

A dedicated computerized tester on Rafael premises is used to carry out electrical tests of integrated propulsion systems. The tester automatically conducts tests, such as:

- Response time of the thrusters
- Heaters' resistance
- Calibration of pressure transducers
- Threshold voltage for actuation of valves

The tester provides a report which includes all test results and the respective requirements.

Propellant Loading – Launch Campaigns

Rafael has worldwide expertise and heritage in propellant loading of Satellites and Launchers (Hydrazine and Xenon). This includes Israel, Russia, French Guiana and India.

Quality Management

Quality Management

Rafael places major emphasis on the high quality of its products.

Rafael maintains an extensive Quality System in order to achieve the customers full satisfactory and to provide them high-quality products. The quality system is integrated through all Rafael's divisions and departments, as well as through all the processes and activities. The quality perception and objectives are applied to the products from the early phases of design and development till the end of the life cycle.

Rafael's Quality System is described in detail in Rafael's Quality Manual.

Rafael Quality system is certified to ISO 9001:2015/AS9100D.

Rafael is also certified to a variety of standards that complies with the management directives, the authority's obligations and the welfare of the employees. For example: environmental [ISO 14001:2015], safety [OHSAS 18001:2007], special activities [NADCAP] and so on. The complete standards that the company is certified is available in the official website.

The Rafael Quality System is documented in a comprehensive procedures system which complies with the above mentioned international/national standards requirements.

CERTIFICATE

This is to certify that the quality management system of

RAFAEL ADVANCED DEFENSE SYSTEMS LTD.

Central Office: David Institute Haifa, 3102102, Israel

Has been audited and registered **in accordance with the requirements of AS9104/1 Rev.2012-01**
The Standards Institution of Israel is accredited under the Aerospace Registrar Management Program and declares that the quality system of the above named organization is in conformance with:

ISO 9001:2015/AS9100D

The quality management system is applicable to

Design (hardware & software) and manufacture of: missiles, weapons, air defense systems, electro-optic systems and components. Communications, command & control and electronic warfare systems. Network centric warfare, platforms and protection systems. Propulsion explosive and space propulsion systems and components. Advanced material and processes. Information technology. Testing range, logistic service and support.

Certification Structure: Campus

Initial Approval:	14/04/2013		
Re-certification Approval:	29/05/2020	**Certificate No.:**	98145
Valid Until:	28/05/2023	**EAC Code:**	18/19/21/33/33

SII-QCD assumes no liability to any party other than the client, and then only in accordance with the agreed upon Certification Agreement.
This certificate's validity is subject to the organization maintaining their system in accordance with SII-QCD requirements for system certification. The continued validity may be verified via scanning the code with a smartphone, or via website www.sii.org.il. This certificate remains the property of SII-QCD.

Dr. Gilad Golub
CEO

Avital Weinberg
Director, Quality & Certification Division

ANAB ACCREDITED MANAGEMENT SYSTEMS CERTIFICATION BODY

IAF

The Standards Institution of Israel

Page 1 of 4

Our Vision: To Enhance Both Global Competitiveness of our Services, with our Uncompromised Quality and Integrity

Space Quality Management

Space products are inherently designed to perform in an extremely environmental conditions (radiation, vacuum, temperature etc.) thus, these products have to acquire adequate quality requirements, in order to function perfectly, and without any anomalies.

The quality perception regarding space products, is derived from Rafael quality policy, with modifications and adjustments from common space quality standards (mainly ESA), in order to provide products and services in accordance with the customer's requirements and expectations.

The customer is in the center of the Rafael's space line managerial attention. The customer is regarded as a partner, and his satisfactory throughout the project is a matter of a high intention. The common project teams work closely together, in full coordination from the early design phase to products deliveries and after supply services. There is a full transparency regarding the products and the information that are delivered at the project meetings and milestones.

A Significant effort is made by the company in order to meet this goal: advanced testing and assembly facilities, training and qualification of skilled technical personnel, strict control of workstations and processes, methods that aims on continuous improvement and so on.

all the space products are 100% inspected, starting from raw materials to final integration. the quality system is organized to fully support the unique requirements of the space products.

The quality system integrated into the ERP system, thus it enables full traceability from raw material to the delivered item. The data that can be retrieved covers many aspects like: serviceability tags for each step, operators in each work station, applicable procedures in each production or assembly step, related reports, deviations and so on.

A PA manager is assigned to every project or program. The PA manager leads all the quality management and related activities such as integration of the quality activities between production, engineering and other supply chain departments. the PA manager is also the POC to the customer in all the product assurance activities (reviews, audits, NCR's, RFD's etc.).

For each and every project there is a dedicated quality program that includes the following chapters, depends on the project scope and complexity.

- QA Plan: Setup, Objectives and Organizational Structure
- Product Approval – Development and Qualification
- Quality Records
- Configuration Control
- Failure Report, Corrective or Preventive Actions
- Audit Program
- Traceability
- Marking
- Calibration
- Cleanliness and Contamination
- Statistical Quality Control and Analysis
- Handling and Storage
- Materials, Mechanical Parts And Processes
- Critical Items and critical Processes
- Limited Life Items
- Sub-Contractors
- Personnel – Training and Certification
- Software Product Assurance
- Electrical, Electronic and Electromechanical Parts
- Testing
- Deliveries
- End Item Data Package (EIDP)
- Program Reviews
- Configuration and Data Management
- Reliability Plan, RAMS, FRACAS
- Customer Property
- Alerts
- Safety

RAFAEL

Manor-Advanced Defense Technologies Division

Tel: +(972)73-335-7263

Email: manor@rafael.co.il

HQ Tel: +(972)73-335-4714

Fax: +(972)73-335-4657

Email: Intl-mkt@rafael.co.il

www.rafael.co.il

UNC.28503/0524/M5/01 ENG/ Studio | MSS