Design of an Affordable Hydrogen Peroxide Propulsion System for CubeSats

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The CubeSats market is continuously growing in recent years pushing the need to provide this class of satellite of propulsion system for orbit maneuverability. In this context, Green Propellants' chemical monopropellant propulsion systems are a competitive solution with respect to more popular electric propulsion systems. In this paper, the design of an affordable propulsion system for CubeSats powered by Hydrogen Peroxide is presented. The design focused on the storage subsystem and the thruster. An innovative modular cubic tank of 1 U volume is proposed, which permits to increase the performance capability of the propulsion system. The designed solution offers a simple and low-cost blowdown propulsion system characterized by an envelope volume of 1.5 U, a dry mass of 0.9 kg, a propellant storability of 0.7 kg of HTP up to 98% wt., a level of thrust of 0.5 ÷ 0.125 N, a specific impulse of 160 s and an of 304 m/s for a 3U CubeSat. The propulsion system powered by HTP presented in this paper is considered a valid competitive option with the other monopropellants propulsion systems existing in the market of propulsion systems for CubeSats. The outcome of the design phase represents a step toward the manufacturing and test of the propulsion system presented.

I. Nomenclature

ADN	= Ammonium Dinitramide
BOL	= Beginning-of-life
CAD	= Computer Aided Design
CDS	= CubeSats Design Specifications
CHIPS	= CubeSat HTP Innovative Propulsion System
COTS	= Components Off The Shelf
EOL	= End-of-life
ESA	= European Space Agency
HAN	= Hydroxylammonium Nitrate
HTP	= High Test Peroxide
LEO	= Low Earth Orbits
MEOP	= Maximum Expected Operating Pressure
PulCheR	= Pulsed Chemical Rocket
R&D	= Research and Development

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TRL = Technology Readiness Level

II. Introduction

Nowadays, CubeSats have become one of the major small satellite players in the space industry [1], thanks to their standard unit size, simplicity, and low cost. Their applications range from earth observation to scientific, technology, and communications missions. Moreover, the increasing trend to consider CubeSats for LEO orbits and mega-constellations has led to the need to provide this class of small satellites of propulsion system to enable their orbit maneuverability. Today, only few nearly off-the-shelf European propulsion solutions exist fostering the need for research activity on new propulsion systems solutions. In this context, the European Space Agency launched a call named "Innovative Propulsion System for CubeSats and MicroSats" with the aim to identify the most promising European Propulsion Systems for CubeSats and/or MicroSats currently available at the technology concept level and assess its TRLs through developments and testing activities, with the ultimate objective to minimize development risks before entering qualification, production, and commercialization phases. The University of Pisa participated in this ESA call with CHIPS project (CubeSat HTP Innovative Propulsion System) proposing a chemical monopropellant propulsion system for CubeSats which uses high-performance hydrogen peroxide up to 98% wt. as the propellant.

Compared to electric propulsion systems, chemical ones have the advantage to provide high thrust-to-weight ratio. This allows the ability to enable impulsive maneuvers as well as attitude control. Moreover, chemical propulsion systems typically require low power consumptions for their operations contrary to electric solutions. CubeSats present severe constraints in terms of power, volume, mass, and costs. Therefore, a chemical propulsion system represents an optimal solution to provide maneuverable capability to this class of satellites.

Among the chemical propulsion systems, monopropellants solutions are the most suited for CubeSats applications for their compactness and simplicity. Their working principle consists of catalytically decomposing a liquid propellant into a high-temperature gas that expands through a nozzle generating thrust. Typical liquid propellants with flight heritage are hydrazine, not toxic nitrate blend propellants, and hydrogen peroxide. Their main characteristics are highlighted in Table 1.

Table 1: Different Propellants Propulsive Characteristics [1,2]

Propellant	Hydrazine	AF-M315E	LMP-103S	98% wt. H2O2
Theoretical Specific Impulse [s]	242	266	252	185
Density @20°C [g/cm3]	1.01	1.47	1.24	1.4
Adiabatic Flame Temperature [K]	1183	2070	2054	1222

Hydrazine thrusters have been extensively used in the past [3] thanks to their high-performance capability. However, hydrazine is highly toxic and carcinogenic and presents the risk of spontaneous decomposition due to its metastable nature, therefore their handling requires expensive protection and safety hardware and precautions, incompatible with the budgetary limitations of CubeSats. Not toxic nitrate blend propellants are a class of green propellant presenting higher density-specific impulse than hydrazine [1,4]. Still, their major advantage relies on their lower toxicity and flammability, which translates into fewer safety measures. However, this type of propellants has a very high decomposition temperature (above 2000 K [5]) subjecting the catalytic bed and the chamber to high thermal stresses. For this reason, special expensive materials and protective coatings must be used for the realization of the thrust chamber and electrical pre-heating of the catalyst is required that in turn implies higher power consumptions. As a consequence, the use of this class of propellants is costly and challenging for CubeSats applications due to their mass and power constraints. Hydrogen peroxide is a non-toxic and low-cost propellant, with long flight heritage. At high concentration, this propellant presents a lower specific impulse compared to hydrazine and nitrate blends, as highlighted in Table 1. However, thanks to its high density, hydrogen peroxide offers performances comparable to those of the two aforementioned types of propellants. Therefore, hydrogen peroxide is a promising option for CubeSats propulsion system due to its easiness to handle and its relatively low decomposition temperature (900-1300 K), which allows to avoid the use of expensive materials for the combustion chamber. Consequently, the cost of the end product of a propulsion system powered by HTP will be lower compared to solutions that make use of other monopropellants. The simplicity and low cost were two key points that permits CHIPS project to be funded by the Agency.

The University of Pisa has a long heritage in research activity on propulsion systems fed by high-density hydrogen peroxide [6–10]. The University's main contribution in the research field of micro propulsion scalable to CubeSats applications was given by the recent PulCheR (Pulsed Chemical Rocket with Green High-Performance Propellants) project [8,11,12]. PulCheR was co-funded by the European Union Seventh Framework Programme. The project demonstrated the feasibility of a pulsed high-density hydrogen peroxide propulsion system capable to provide 1 N thrust. In that project framework, the most promising catalytic bed configuration was Platinum covered Alumina pellets [12,13]. The design of the catalytic bed for hydrogen peroxide decomposition is the most critical aspect for the development of effective monopropellant rocket thrusters as it involves the evaluation of a delicate trade-off between several complex, interactive, and conflicting requirements.

Starting from the PulCheR heritage, the CHIPS project aims to design, manufacture and test a propulsion system for CubeSats powered by HTP up to 98% wt. The objective of the project is to demonstrate a proof of concept. Therefore, the aim is to verify the proposed solution functionality through tests in atmosphere and vacuum achieving a TRL higher than 3. The outcome of the project wants to propose an affordable product which key features are the simplicity and low cost that is competitive to other propulsion systems for CubeSats present in the market.

The present paper focuses on the design of the propulsion system. The paper aims to highlight the key aspects of the CHIPS propulsion system solution with particular focus on its simplicity and affordability. Therefore, in the first part of the paper the design driving factor and propulsion system main requirements are highlighted. Then the design attention is focused on the propellent storage subsystem and thruster. The rest of the components for the propulsion systems are COTS products and they are listed. The outcome of the design is then summarized in terms of propulsion system specification. The last part of the paper is focused on the propulsive performance prediction of the designed solution and cost estimation is done.

III. Propulsion System Design

The propulsion system design driving factors were:

- Maximization of the propulsive performance
- Minimization of the dry mass
- Low cost
- Simplicity

Based on the ESA “Innovative Propulsion System for CubeSats and MicroSats” call requirements and design driving factors, the University of Pisa determined the requirements for the CHIPS propulsion system listed in Table 2

Table 2: CHIPS Main Requirements

Parameter	Requirement
Propellant	HTP 98% wt.
Specific Impulse	>150 s
Power Consumption	≤ 5 W
Thrust	≤ 0.5 N
Minimum Impulse Bit	≤ 25 mN s
Propellant Volume	≥ 0.3 dm^3
MEOP	≥ 24 bar

Parameter	Requirement
Dry mass	≤ 1.2 kg
Volume Envelope	≤ 2U
Material HTP compatibility	Grade I and II
Lifetime	≥ 3 yrs
Propellant Management Operation	Blow down
TRL	≥ 3
Overall Price	≤ 50k€

The definition of the requirements was in line with the design driving factors. Indeed, the stringent requirements on propulsion system maximum dry mass and envelope volume push to avoid the use of complex and high volume requiring propellant pressurization systems for the CHIPS propulsion system. For this reason, the first design choice was oriented in making a blowdown system. This choice permits to develop a monopropellant propulsion system characterized by simplicity. In a blowdown system of such type the propellant is stored inside the tank tighter with a limited amount of pressurizing gas and these two substances are separated by a barrier (generally made with elastomeric materials) capable of deforming to allow the gas to pressurize the propellant. A drawback of this configuration is the impossibility to maintain the system pressure constant during the operations, and this produce a decrease in the thrust level as the tank empties. However, with an appropriate system design this drawback can be dammed up, making the system give a thrust level inside the wanted range both in BOL and EOL conditions. Then, the propulsion system architecture was defined, and it is shown in Fig. 1.

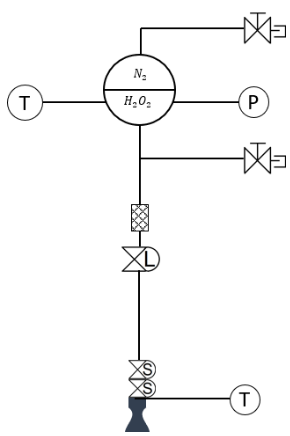

Fig. 1: Schematic Representation of CHIPS Propulsion System

Fig. 1 shows the main components of the CHIPS propulsion system. The system configuration is composed by one storage subsystem, two fill and drain valves, one filter, one latch/isolation valve, two solenoid valves, one thruster, one pressure transducer, one temperature transducer, one surface temperature sensor. The model philosophy adopted for the propulsion system was Engineering Breadboard model to reach the TRL higher than 3. The development of such a model permits to use COTS product that are not qualified for space applications. However, among the propulsion system components listed above, no COTS product was found for the storage system. Therefore, it was chosen to perform a R&D activity focused on the design of a custom tank. The thruster was the other element that was decided to design thanks to the past heritage of the University of Pisa on the PulCheR [9,11].

A. Tank Design

Based on the propulsion system requirements and design driving factors the tank requirements were determined and they are listed in Table 3.

Table 3: CHIPS Tank Main Requirements

Parameter	Requirement
Expulsion Efficiency	≥ 90 %
MEOP	≥ 24 bar
Propellant Volume	≥ 0.3 dm^3
Volume Envelope	≤ 1U
Dry mass	≤ 1 kg
Propellant Volume	≥ 0.3 dm^3
Material HTP compatibility	Grade I and II
Operating Temperature	-10 ÷ 40 °C
Propellant Management Device	Blowdown PMD

The first step of the tank design was to select the MEOP pressure level that was fixed to 24 bar. Then the blowdown ratio was fixed to 4, and assuming an isothermal expansion of the gas during operations, also the ratio between the initial gas volume and the final gas volume was found. So, a trade-off was performed to find the best combination in terms of tank shape, thickness, material, and propellant management device, to maximize the performances of the propulsions system satisfying the requirements of table. The trade-off focused cylindrical, spherical, and cuboidal tank shape and on the propellant management device selection between diaphragm or bladder. The final choice fell on a cuboidal bladder configuration tank, with some internal structural reinforcements, made in Al 5254 H34. This choice permits to maximize the propulsive performance in terms of velocity increment and total impulse. The Al 5254 H34 aluminum alloy was selected as the best material compromise in terms of HTP compatibility (Class I) and mechanical properties. Moreover, the selection of a Class I compatible material with HTP permits to satisfy an important assurance requirement taken from CDS [14] for which three barriers are needed between the propellants and the thruster to avoid catastrophic events. Indeed, the HTP is a chemically unstable substances that reacts spontaneously and its decomposition is greatly accelerated by some materials. Unfortunately, among them there also some useful aerospace materials, such as Ti6Al4V, Al7050 and also 316 SS (if not correctly passivated), and so using these materials for building the tank can be very dangerous. The bladder confines the HTP from the rest of the system. Therefore, if the bladder is perforated and the HTP is poured into the tank shell, it will enter in contact with the tank shell material. For this reason, the selection of a Class I tank material compatible with HTP permits to avoid a sudden decomposition of the HTP. Otherwise, the break of the bladder could produce a catastrophic event due to the catalytic decomposition of HTP entering in contact with the tank walls of no-compatible material, without any possibility of inhibition. The cuboidal shape is very unpopular for a pressure vessel. Indeed, a pure cubic shell under internal pressure behaves as plate with clamped edges. Therefore, it is characterized by high stresses at the center of the edges and high deformation at the center of the faces. However, the internal structure solution adopted for the CHIPS cuboidal tank demonstrated through analysis performance comparable with cylindrical tank. In particular the adopted shape showed a more volumetric efficiency and a high level of modularity, thanks to its shape that exploits and interfaces perfectly with the volumes of a CubeSat. This kind of tank is also able to respect both the requirements on maximum envelope and dry mass, thanks to the low-density material chosen and to the reinforcements used that allow to significantly reduce the thickness of the tank walls.

B. Thruster Design

The determined thruster requirements are listed in Table 4.

Table 4: CHIPS Thruster Main Requirements

Parameter	Requirement
Operational Temperatures	≤ 1000 °C
MEOP	≥ 18 bar
Thrust	≤ 0.5 N
c^* efficiency	≥ 0.90
Operational Mode	Continuous firing
Operational Mode	Pulse mode
Total throughput	≥ 0.4 kg
Volume Envelope	≤ 1U

The CHIPS propulsion system is a monopropellant, so the thruster consists in combustion chamber made of a catalytic bed where the propellant decomposes in a gas mixture that is accelerated through a nozzle. The first step of the thruster design was to select the thrust level at BOL which was set to 0.5 N. A conical nozzle was selected which area ratio was fixed to 70. Then the thruster was preliminary sized using the classical 1D propulsive performance equations assuming a c^* efficiency to 0.9, a thrust coefficient efficiency of 0.9, vacuum conditions and using the BOL and EOL condition from the tank design choices. The combustion chamber pressure was set to roughly 18 bar at BOL considering conservative pressure losses between the tank and the catalytic bed. The thrust at EOL was predicted to be 0.125 N and the mass flow rate range 0.4 ÷ 0.05 g/s at BOL and EOL respectively. The catalyst selected was Pt-α-Al2O3 pellets which has past heritage from the PulCheR project [12,13]. This catalyst solution is characterized by high resistance to thermal stress. The catalyst manufacturing is developed in collaboration with the Department of Chemistry of the University of Pisa. The thruster configuration was scaled from PulCheR heritage. The sizing of the catalytic bed, the overall decomposition chamber and the nozzle was based on the scaling down of the thruster developed during the PulCheR project. During operations the temperature inside the decomposition chamber reaches values close to 1000° C. If placed too close to the tank or line where the HTP is located, the high heat source would produce catastrophic events, as the non-return temperature of the HTP for the activation of a self-sustained thermal decomposition is about 100 ° C. Moreover, the passivation film of 316 SS components of the line begins to break around 40 ° C, thus allowing the HTP to be able to catalytically decompose. Then, the thruster could not be mounted directly on the tank closure plate like the rest of the system but have to be pushed away from it by means of rods. The design of these rods followed a fairly complex process, having to find the right combination of thickness, length and material to respect the constraint of having a propulsion system that occupies a maximum volume of 2U that ensures an operating temperature of the tank below 40 ° C. Moreover, the rods need sufficient thermal conductivity to ensure that most of the heat soak-back is taken from them rather than from the feed line. The rods will connect the thruster and the tank were designed to be interfaceable with both the elements by means of screws and threads, to satisfy the requirement about the easy disassembly and replacement of the propulsion system components.

C. Propulsion System Components Selection

The COTS selection for valves and sensors composing the CHIPS propulsion system was aimed at satisfying the requirements of volume, mass and power consumption, Table 2. In particular, to satisfy the requirements on the total propulsion system, lower levels requirements were attributed to each component. Among these requirements the main ones are:
Component mass less than 0.1 kg.
Component envelope volume less than 0.5 U.
Component power consumption < 3 W
Component material compatible with HTP.

The main characteristics of the selected COTS for CHIPS are reported in Table 5. From this table it is very easy to see that the imposed requirements are fully satisfied.

Table 5: CHIPS COTS

Part	Mass (kg)	Envelope (mmxmmxmm)	Power (W)	Material	Sealing
Filter	0.003	7.5x13x8	N/A	316 SS (body and filter)	Teflon
Isolation Valve	0.006	33x7x7	0.5	316 SS	Viton
In-line Valve	0.006	33x7x7	0.5	316 SS	Viton
Firing Valve	0.006	33x7x7	0.5	316 SS	Viton
Propellant Fill and Drain Valve	0,023	48x20x15	N/A	Aluminum	PTFE
Gas Fill and Drain Valve	0,01	18x15x8	N/A	316 SS	Teflon
Pressure Transducer and Temperature Sensor	0.01	40x14x14	0.4	316 SS	Teflon
Surface Temperature Sensor	<0,01	Custom.x0.5x0.5	0,2	Ceramic	N/A

The temperature sensor and the pressure transducer have to be interfaced with the tank, to record the pressurizing gas temperature and pressure. To make this interface possible threaded holes were foreseen in the closure plate of the tank, that represents the only face of the cube welded to the rest of the structure and not generated as a piece. However, this plate presents a sealed no-welded removable central disk that permits the insertion and removal of the bladder. Another threaded hole is necessary on this plate to guarantee the interface for the gas fill and drain valve. The valves and filter composing the feed line are linked by fittings of suitable dimensions for the CHIPS application, and no welded tube is foreseen along the feed line. The propellant fill line is connected to the feed line at the filter downstream by an on/off valve with threaded connection. The use of all these threaded interfaces and non-welded connections assures the easy substitution of all the components of the propulsion system. This characteristic is also very useful in case of damage during the test campaign. The pressure loss along the feedline is relatively small and assures to reach inside the decomposition chamber a sufficient high pressure, that was demonstrated [9] to be enough to trigger the HTP decomposition in a very short time and to reach quickly the steady state conditions.

D. Propulsion System Rendering & Specifications
Figure 1 shows the CHIPS propulsion system design mounted inside a 2U CubeSat envelope.

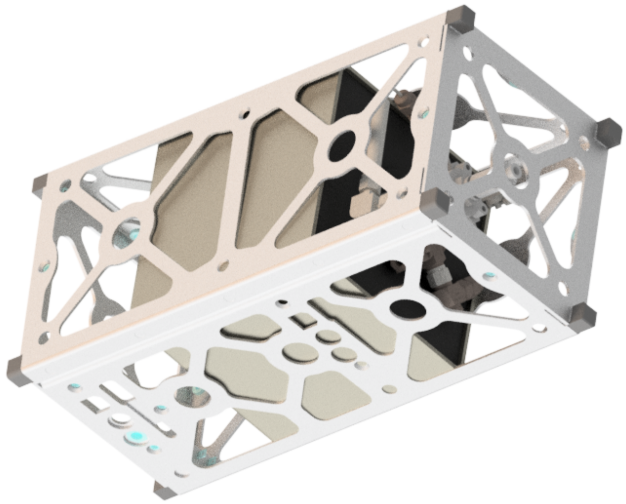

Figure 1: Propulsion system rendering inside a 2U envelope (mettere fonte telaio).

The designed propulsion system specifications are summarized in Table 6.

Table 6 Propulsion System Specifications

Parameter	**Specification**
Propellant	98% wt. H2O2
Catalyst	Pt-α-Al2O3 pellets
Operational mode	Blowdown mode
Tank MEOP @BOL	24 bar
Combustion Chamber MEOP @BOL	18 bar
Blowdown ratio	4:1
Specific impulse	160 s
Characteristic Velocity	909 m/s
Characteristic velocity efficiency	> 0.9
Thrust Coefficient efficiency	> 0.9
Nozzle expansion ratio	70
Adiabatic HTP decomposition temperature	1200 K
Propellant density	1.4 kg/m^3
Nozzle type	Conical

Parameter	Specification
Thrust	0.5 N (@BOL)- 0.125 N (@EOL)
Propellant mass flow rate	0.32 g/s (@BOL) – 0.08 g/s (@EOL)
Propulsion system total dry mass	0.9 kg
Propulsion system total envelope	1.5 U
Propulsion system total power consumption	5 W
Propellant mass	0.710 kg
Expulsion Efficiency	> 0.9
Tank Internal Volume	0.68 dm^3
Tank Propellant Volume	0.51 dm^3

IV. Propulsion System Performance

To evaluate the system performance a 3U CubeSat was considered with the CHIPS propulsion system occupying 1.5 U. Therefore, to estimate the velocity increment, the total impulse, the minimum impulse bit the mass, the remaining 1.5 U mass was fixed. Considering that the maximal allowable mass for 1U is 1.33 kg [14], a payload mass of 2 kg was set. Considering the design propulsion system specification of Table tot, the expected propulsive performances are listed in Table 7.

Table 7 Propulsion System Performance

Parameter	Requirement
Δv	306 m/s
Total Impulse	1003 N s

The MIB were not evaluated since it is not simple to estimate its value through mathematical modeling. The MIB value will be evaluated during the test campaign. After the expected performance evaluation, the attention focused on the assessment of maneuver capability of a 3U CubeSats provided with CHIPS propulsion system. The results are listed in Table 8. The reference data reported in table tot are from [15].

Table 8 CHIPS maneuver capabilities

Maneuver	Value	CHIPS case
Orbit change		
Altitude change	0.5-0.6 m/s per km in LEO	About 510-610 km of altitude change using all the available propellant
Plane change	135 m/s per degree	About 2,27° of plane change using all the available propellant

Orbit control		
Drag compensation @ 300 km altitude	0.1-0.4 km/s/yr	Guarantees 3-1 years of drag compensation
Drag compensation @ 500 km altitude	4.4-25.8 m/s/yr	Guarantees at least 3 years of drag compensation

To conclude the performance evaluation, the Δv capability of the designed propulsion system mounted on a 3U CubeSat considering different propellants was investigated. The performance comparison was made for the propellants of Table 1, i.e. HTP 98% wt., Hydrazine, AF-M315E and LMP-103S. The computations were performed considering the propellants nominal data values of Table 1 and the data of Table 6. To evaluate each propellant mass, isothermal expansion of the gas during operations was assumed as well as 100% expulsion efficiency. Figure 2 shows the Δv comparison results.

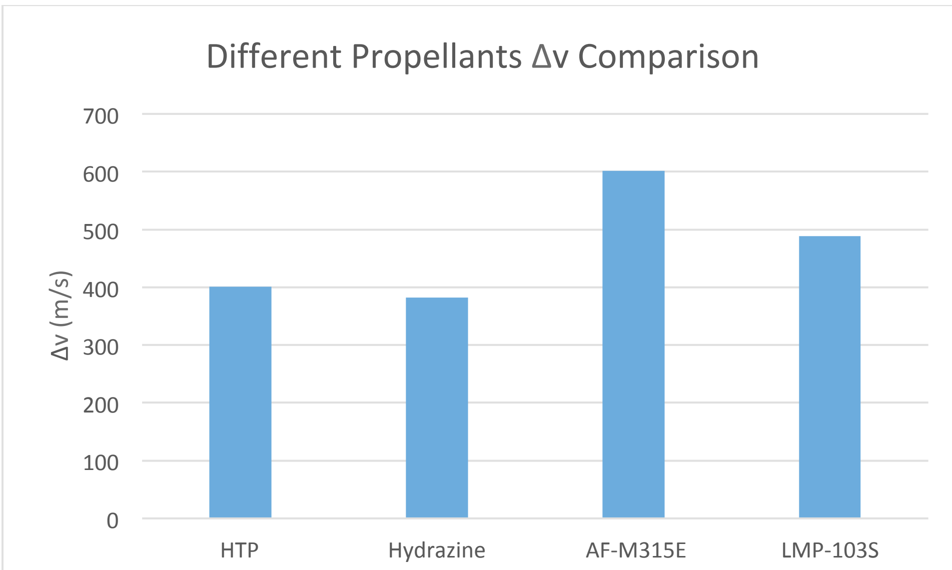

Figure 2 Δv capabilities with different propellants

The results of Figure 2 highlights the HTP advantages stated in the introduction. Indeed, despite the higher value of specific impulse given by the hydrazine, the HTP allow to reach higher Δv than Hydrazine thanks to its higher density which increments the volumetric specific impulse. This aspect, together with the toxicity of hydrazine, makes HTP a valid solution for CHIPS. However, the Δv given by HTP is lower than the one given by AF-M315E and LMP-103s, because they present densities comparable with HTP and higher specific impulse than HTP. Nevertheless, the HTP remains the best propellant option for the CHIPS propulsion system, since, as stated in the introduction, the ADN/HAN based propellants such as AF-M315E and LMP-103s have higher decomposition temperatures than HTP, and this produce three effects: the first is the necessity of using a pre-heater mechanisms of the catalytic bed and the impossibility of doing cold starts, that produce an increment in propulsion system mass and power consumption; the second is the higher thermal stress on the catalytic bed, that can reduce significantly the lifetime of the propulsion system; the third is the increment of costs due to the increased complexity of the system. These disadvantages are not counterbalanced by the higher Δv offered, because, as highlighted in Table 8, the Δv given by HTP is sufficient to accomplish all the maneuver required for a CubeSat. Therefore, there is no need to reduce the system lifetime and increase its power consumption to obtain better performances. For all these reasons, the HTP was considered the best propellant solution to meet all the requirements of the CHIPS project and design driving factors.

V. Propulsion System Lifetime and Cost Estimation

The CHIPS propulsion system end product cost target is lower than 50k€, as reported in the requirement Table 2. Therefore, a rough cost estimation was made at the end of the design in order to meet the cost requirement. This preliminary cost estimation and lead time for the various system components is reported in Table 9.

Table 9 CHIPS propulsion system cost estimation

Components	Estimated/Target Cost
Tank & Fluidic Line	5 ÷ 10 k€
Two Fill & Drain Valve	1 ÷ 2.5 k€
One Pressure Transducer	2 ÷ 4 k€
Temperature Sensor	0.2 ÷ 0.5 k€
Isolation/Latch Valve	1 ÷ 2.5 k€
Two Solenoid Valve + Filter	2 ÷ 8 k€
One Thruster	2 ÷ 5 k€

The cost estimation of Table 9 is based on COTS product quotations, manufacturing quotations and heritage expertise. The cost estimation of the end product is in line with the requirements. The possibility to use COTS components not qualified for space applications permits to maintain low the cost of the CHIPS propulsion system. Anyway, the numbers of Table 9 are just an estimation. The end product cost could differ but based on the acquired experience it will not be far from 50 k€.

VI. Conclusions

In this paper the design of an affordable propulsion system powered by hydrogen peroxide for CubeSats was presented. The activities played in the framework of the CHIPS (CubeSat HTP Innovative Propulsion System) project of the University of Pisa funded by the European Space Agency. Maximizing the performance, reducing the dry mass, simplicity and low cost were the design driving factors. After the propulsion system requirements identification, the design choices were highlighted. HTP up to 98% wt. was selected as the propellant and a blow-down propulsion system configuration was selected for its simplicity. Being a Technology Demonstration project not qualified COTS products compatible with HTP were selected. The design activity focused on the development of a modular tank which outcome was a cuboidal shape in Al 5254 H34 that proved by analysis to store the highest amount of propellant for 1U envelope and guarantee the highest propulsive performance. Thanks to the heritage of the University of Pisa, the thruster was the other component designed in house. The outcome of the design was a propulsion system characterized by an envelope volume of 1.5 U, a dry mass of 0.9 kg, a propellant storability of 0.7 kg, a level of thrust of 0.5 ÷ 0.125 N, a specific impulse of 160 s. Considering a 3U CubeSats the CHIPS propulsion system was expected to achieve Δv capability of 304 m/s that permits to perform typical manoeuvre for CubeSats in LEO environment. The advantage of HTP with respect to other propellants competitors such as hydrazine and ADN/HAN based propellants was highlighted through performance comparison of the CHIPS propulsion system Δv capabilities changing the propellant. From the comparison emerged the potentiality of HTP in propulsive terms and its selection was even more justified based on the design driving factors of simplicity of the system and low cost. Finally, a rough cost estimation was done which outcome was a propulsion system for CubeSats that cost less than 50 k€. The authors of these papers are convinced that CHIPS propulsion system represents a potential competitive option in the European CubeSats propulsion system market thanks to its simplicity a low cost. Moreover, the design choices permit to increase its propulsive performance. Indeed, more than one tank can be interfaced in a modular way thanks to its cuboidal 1 U shape and the thruster can be changed to achieve other thrust level requirements. Therefore, the propulsion system could be adapted for different missions and for different CubeSats sizes. The next activities of the project will consist of the propulsion system manufacturing and assembly in order to test it in atmosphere and vacuum environment.

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