Thesis Proposal and Plan

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Abstract

This project will focus on the demonstration of a solar thermal propulsion (STP) thruster as part of the final thesis of the master track Space Flight Engineering at Delft University of Technology (DUT). This document describes the proposal for this thesis and is concurrent to the literature study. It will show the lay-out, goal and research question for the thesis. In the literature study, research about STP was reviewed, an STP tool was developed and effort was put into data acquisition. This laid the foundation for the thesis, which will take approximately 7 months. The goal is to demonstrate the feasibility of STP by improving the design of Solar Thermal Thruster 1 in terms of specific impulse. The research question is: "How accurate does the STP tool predict the thruster performance?". The thesis will kick off with the design of STT2, which is simultaneous to the tool enhancement and manufacturing phase. Once these are completed, the thruster will be subject to experiments, after which the data will be analysed. In the end, conclusions will be drawn regarding the goal and research question and recommendations will be given.

1 Introduction

Starting with the launch of the Sputnik in 1957, space exploration has been dominated by large spacecraft for decades [1]. However, nowadays the trend is turning towards the smaller satellites because of the lower cost associated with them. CubeSats and the even smaller PocketQubes are playing an ever increasing role in these so-called nano-satellites [2] [3] [4]. This trend is illustrated in Figure 1, where the (predicted) number of nanosatellite launches is shown [5].

CubeSats and PocketQubes are nanosatellites in the 1-10 kg range [6]. They are made up of one or more cubes, 10x10x10 cm^3 for CubeSats and 5x5x5 cm^3 for PocketQubes. Proposed in 2000, the small satellites prove to be an excellent demonstration platform for universities such as Delft University of Technology (DUT) [7]. Due to the miniaturization and the modular character, the nanosatellites can be developed relatively easy and launched relatively cheap. DUT started working on the subject in 2004 [8], resulting in the launches of Delfi-C^3 (2008) and Delfi-n3Xt (2013).

The launch of a triple cube PocketQube is planned per 2019. While for launches smallsat developers still rely greatly on so-called piggyback rides [9], there are also dedicated smallsat launches by commercial companies in the last few years, showing the great interest in the nanosatellite business [10] [11] [12].

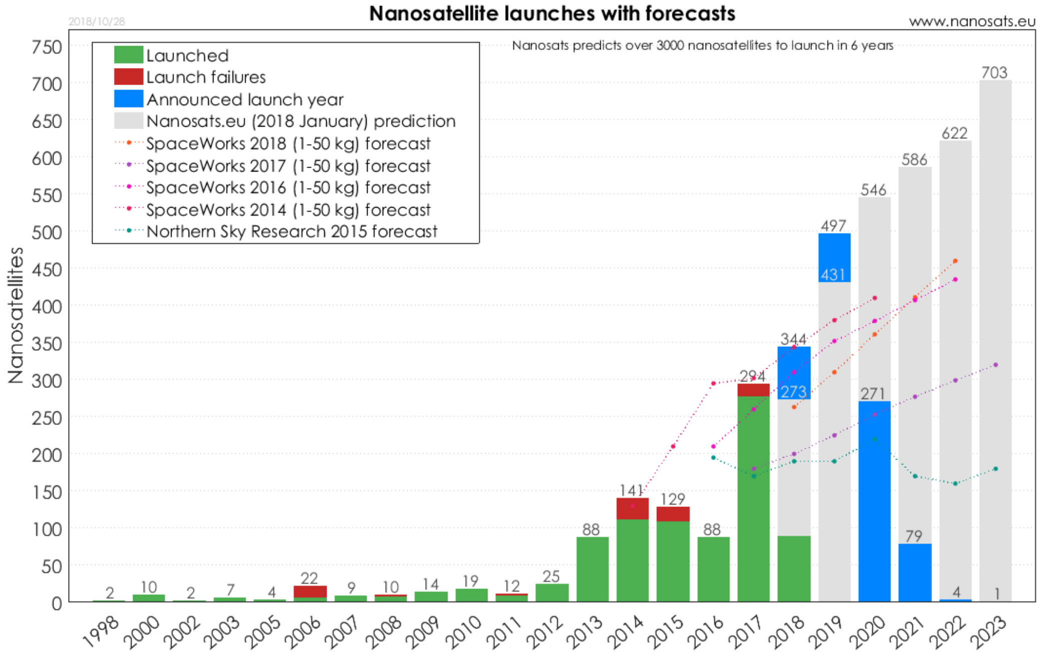

Figure 1: (Predicted) number of nanosatellite launches [5].

Demonstrated in the latter two DUT satellites are micro-propulsion thrusters, which are thrusters that deliver thrust (pulses) in the micro-Newton range or even lower [13]. These Delfi subsystems were partially developed by DUT. Because of the steady rise in use of nanosatellites (see again Figure 1 [5]), great interest is also taken in these subsystems which can provide a small satellite with the capability of orbit transfers, maneuvers, station-keeping and other [2]. One of the contenders is the concept of Solar Thermal Propulsion (STP), which is an excellent contender to test on a smallsat due to the relatively low development and launch costs mentioned earlier [14] [15].

STP shows great potential to overthrow the current propulsion types available, which are mostly chemical, electric and resistojet (thermal) thrusters [16] [17]. STP has a higher thrust-to-weight ratio than electric propulsion and a higher specific impulse than chemical propulsion, according to Leverone et al. [2].

Furthermore, Leverone shows that STP can compete with the above-mentioned resistojets, both in the areas of efficiency and thrust. Resistojets are engines that heat a monopropellant by a resistor (hence the name), after which the propellant is expelled to create thrust. Comparable to STP, it has been researched since the second half of the twentieth century [18]. However, it does have flight heritage on large spacecraft, which STP does not. In the current century, it has emerged as an alternative propulsion system for nanosatellite applications, as STP has. Nowadays, resistojets have flown on a few CubeSats, but research is still being conducted [19] [20] [21] [22] [23]. The company Busek built a micro resistojet in 2013, having a specific impulse of 150 s, thrust of 10 mN and system mass lower than 1.25 kg [24]. The Technology Readiness Level (TRL) was set at level 5, which means the microthruster has been validated in a relevant environment. As a comparison, TRL has a TRL of 3. Values for existing STP thrusters are unfortunately not available for comparison.

The comparison with resistojet micropropulsion is necessary, as they are very similar in their lay-out. Both rely on the heating of propellant via (initially) solar energy, have heat exchangers, attitude issues and the same range of specific impulse and thrust. The most prominent difference is that, in resistojets, solar energy is first converted to electrical energy that heats the propellant, while in STP thrusters, the radiation is directly used to heat the propellant. Skipping the inbetween step for STP thus makes it more efficient, meaning either higher performance or lower concentrator area requirements. This makes ST a viable option for (small) spacecraft operations.

However, STP requires investments in order to be feasible for (nano)spacecraft applications. Issues regarding solar irradiation (eclipses), attitude control (fixed between concentrator and nozzle) and concentrator system (relatively large) need to be tackled in order to make the concept feasible. As mentioned above, STP has never been flown in space, however a demonstration solar thermal thruster (hereby called STT1) was set up by Harry Leenders in 2008 for his thesis at DUT [25].

This demonstration proved successful, but still lacked at some points, the most prominent one being the low specific impulse (I_{sp}) due to the low attained temperatures. The demonstration of a higher specific impulse is adamant to the future success of STP. Possible issues which can be addressed in the design of STT1 to raise the I_{sp} regard the temperature, material, propellant choice, heat source and leak-tightness. The aim of this research is to address (some of) these issues.

STP relies on the heating of propellant. STT1 reached a maximum propellant temperature of 750 K and a maximum thrust of 100 mN while illuminated by a theater lamp. According to Leverone et al., temperatures above 1500 K could be reached [2]. Only 60 W of the 250 W lamp was used according to Leenders, so an increase in this efficiency could either increase the propellant temperature or reduce the flow rate.

Although the total mass of STT1 could not be found, the copper RAC mass alone is already 0.066 kg without the thruster or any propellant. Here, improvement in mass can also be made by finding out what materials can withstand high temperatures while still being (cheaply) available and manufacturable.

Next to that, there were leakages in the nozzle thermocouple (indicating propellant loss) and the propellant channels had a simple straight lay-out. As many improvements can be made on STT1, the aim for this project will thus be to design, build and test a solar thermal propellant thruster, called STT2. This aim will be further worked out.

This document serves as the project plan for the master thesis which will be done on the subject described above. The lay-out is based on references [26] [27] [28] [29]. In the next section, the state of the art of solar thermal propulsion is described in detail. The objective and research question of this research will be presented. This is followed by the methodology to show what path will be followed to get to the desired result and why. Then, the experimental set-up will be discussed, followed by the expected results and outcome. The relevance of the outcome will also be shown in this section. At the end, the project planning is described which will give the reader an overview of the expected conclusions.

2 State of the art

The state of the art of STP will be introduced to the reader here. As was already mentioned in the introductory section, this document is concurrent to the literature study, titled *Feasibility of Solar Thermal Propulsion* [30]. In the report, one can find a detailed overview of STP research since the 1950's (the first mention of STP) [31], followed by a dedicated section towards research at DUT, faculty of Aerospace Engineering.

STP is, in short, a spacecraft propulsion concept which relies on the heating of a monopropellant via

Solar irradiation in order to create thrust. Via a concentrator system, possibly containing mirrors and lenses, it collects the energy in a heat exchanger (the Receiver-Absorber Cavity or RAC), through which the propellant flows. The heated propellant then runs to the nozzle chamber after which it is expanded in the nozzle, propelling the spacecraft. Because the propellant is heated via the (practically) endless power of the Sun, it can achieve higher temperatures (which determines the efficiency partially) than chemical propulsion, which has a fixed amount of energy per kilogram of propellant. As told in the introduction, it also achieves higher efficiencies than resistojets, as the conversion step from solar to electric energy is skipped [2].

Leverone et al. [2], in their latest article, presented an extensive overview of the history of STP, starting at the invention in 1956. What becomes clear from the overview is the involvement of governmental institutes (e.g. Air Force Rocket Propulsion Laboratory (AFRPL), National Aeronautics and Space Administration (NASA)) in the earlier research towards STP, while later on universities (e.g. Italian, Chinese, Dutch universities) put in efforts to the realisation of STP in spacecraft applications.

STP kicked off with the publishing of the article "The solar-powered space ship" by German scientist Krafft A. Ehricke in 1956 [32]. He argued that the use of chemical propulsion would certainly be necessary for space flight (the space race had yet to start), but that it was limited in the energy supply in the sense that rockets had to carry their own supply of "energy" with them. Thus he proposed, next to a nuclear option, the use of reflector collectors. Already at that point Ehricke sees disadvantages in the structure (heavy) and the rigidity of the design (the collector attitudes and thrust direction are coupled). Furthermore, he saw the merits of hydrogen due to its low molar mass as propellant and conducted research towards the specific impulse.

In 1962, the paper published by the AFRPL [33] handed the reader one of the greater reasons STP had not been researched further yet: the investments in the concentrator system were deemed too great (and thus too risky), turning the attention towards other means of space propulsion. Particularly the vehicle integration was "much feared and considered sufficient grounds for the decision that was made". Even today, the vehicle integration of the concentrators (mirrors and lenses) is a disadvantage, one of the reasons it never flew in space. The AFRPL paper also acknowledges that a lower thrust level would mitigate this disadvantage, pushing STP in the direction of micropropulsion. It is one of the reasons the current research will also be for nanosatellite applications.

After a jump in time, JM Shoji discussed several propellants in his STP paper in 1983 [34]. These are: hydrazine, ammonia, methane and hydrogen. Hydrogen proved to be the best performing propellant because of the high specific impulse due to its low molar mass, even at lower temperatures. Furthermore, advice was given regarding the RAC material. Rhenium proved to be a promising material, capable of resisting high temperatures (up to 2700 K), having sufficient strength and being manufacturable. Carbon was also mentioned, but its manufacturability lacks with respect to rhenium.

Starting in the 90's, multiple researchers looked into the so-called bi-modal systems, where the STP subsystem would not only provide propulsion but also power to the spacecraft [35, 36, 37, 38, 39, 15, 40]. The advantage here was to mitigate the use of a separate power subsystem, lowering the overall complexity of the spacecraft. Of course, it increased the complexity of the STP subsystem because it needed to be expanded in order to convert heat to electricity.

In 2003, Japanese scientists Hironori Sahara and Morio Shimizu conducted STP micropropulsion experimental work with a molybdenum solar thruster, heating the thruster to 2300 K with a specific impulse of 800 s [41]. They also came up with an interesting advantage to STP: it is more eco-friendly than its chemical counterpart when using e.g. hydrogen or water. Other research in the field of STP for microsatellite applications can be found in [42, 43, 4, 7].

Apart from the research described above, Delft University of Technology (DUT) also had studies regarding STP, both theoretical and practical. The most noteworthy one, already seen in the introduction, is the practical thesis done by Leenders in 2008. He designed, built and tested a STP thruster, now called Solar Thermal Thruster 1 (STT1), having gaseous nitrogen as the propellant. During testing he used a 1000 W theater lamp, of which 60 W eventually reached the heat exchanger. His motor was simple, having a heat exchanger, nozzle and tubing for the propellant flow. Next to that, it was fitted with several thermocouples, pressure sensors, a mass flow sensor and a load sensor, in order to receive relevant data which was used to determine the performance.

He reached a maximum propellant temperature of 525 K, a thrust of 100 mN and a specific impulse of around 31 seconds at sea level conditions [25] [44]. For recommendations he wrote that a higher power input was necessary, next to a possible channel lay-out change in the RAC and redesign of the RAC shape itself.

The last thing that needs to be noted in this section are the STP propellants that were discussed in the literature study [30]. These four were gaseous ammonia, gaseous hydrogen, gaseous nitrogen and liquid water. It was found that the first two are toxic and introduce explosion hazards respectively. Hydrogen also has a high tank volume requirement due to its high density. However, both gases were most promising regarding specific impulse. Liquid water does not have the hazards of the previous two but instead has complex two phase flow and corrosion risks. Of course, liquid water is freely available and is not toxic. The last propellant under discussion, gaseous nitrogen, has an inert nature, high availability and availability of nitrogen mass flow sensors at DUT. It is thus recommended for studies that are limited in resources (see section on resources).

Summarizing the research here, the standing notion is that STP is a, in theory, promising propulsion concept in the upcoming era of nanosatellites. STP could be a perfect candidate for smallsat missions which require station-keeping or minor but fast orbit changes. While the number of launches of these spacecraft is increasing, the need for a high efficient propulsion subsystem is also growing. While STP may not be ready to be implemented on spacecraft missions yet [39], Mankins [45] showed that the propulsion concept would greatly be benefited by laboratory-based validation experiments, which states the need for this study. For STP to become viable, its efficiency should be validated and potential risks (such as the concentrator subsystem and attitude issues) should be researched and mitigated. The first will be addressed in this study using Leenders' research into STP as a basis. In the next section, the reader will find a more elaborate writing about the goal of the thesis.

One is referred to the literature study for further information about the state of the art and the research at DUT.

3 Thesis statement

In the literature study [30], it was found that STP requires additional research in order to advance towards the level where it will be considered as the means of propulsion for a spacecraft. It was stated above that one way to do this is to demonstrate the performance of an STP thruster via experiments. Thus, that is exactly what will be done in this thesis: design, manufacture and test an STP engine for nanosatellite applications. The motor will be named Solar Thermal Thruster 2 (STT2).

One of the aims of the literature study was to look into possible ways of improvement with respect to Leenders' work. A high-powered heat source was found in the form of a welding laser facility at the faculty of Mechanical, Maritime and Materials Engineering. Furthermore, an analysis towards the performance was done via a created tool, called the STP tool, created in Python and based on the analyses written by Leenders

[46] and Preijde [47]. The analysis showed that the sea-level specific impulse can be raised to 67.0 seconds due to higher power input and a more efficient RAC [30]. The latter can be achieved by using another shape, material and channel lay-out. This specific impulse is reached at a chamber pressure of 2 bar, which is dictated by both Leverone [2] and Leenders. It should be noted that this relatively low pressure has the consequence that high specific impulses (above 100 s) cannot be achieved without increasing the laser power (and thus temperature) to truly high temperatures (over 1500 K), introducing material melting issues.

Because the analysis proved that better performance (specific impulse-wise) can be achieved, the following goal is proposed for the thesis:

Demonstrate the feasibility of Solar Thermal Thruster 2 by doubling the specific impulse.

This demonstration will be done at the hand of multiple tests or experiments, which will be elaborated on in the latter section containing the experimental approach. As described above, the manufactured engine will be backed by the STP tool. There is no validation yet for this tool, so the experiments will be performed to validate it. Thus, the main research question will be:

How accurate does the STP tool predict STP thruster performance?

The accuracy mentioned in the research question can be split into multiple variables; the temperature in the RAC wall, the temperature of the hot gas in the nozzle, the pressure of the hot gas in the nozzle, the created thrust and the resulting specific impulse. Because these will all be monitored by sensors during the experiment (see latter section), it is worth comparing these to the tool output to see whether the STP tool is accurate and can be used for further STP thruster design.

It should be noted that resources during the thesis phase are limited (see also latter section), both money and time wise. It is expected that a demonstration is still a possibility, but the following simplifications will apply during the design:

1. The engine will have no thermal storage, to reduce complexity.
2. The engine will have no concentrator system, because the welding laser is already concentrated and of considerable power.
3. The engine will have no fiber optic cables, to reduce complexity.
4. The engine will not be a bi-modal system (provide propulsion and power), to reduce complexity.
5. The propellant will be gaseous nitrogen, ruling out two-phase flow. Furthermore, nitrogen is non-toxic and available at DUT.
6. The tests will not be conducted in a vacuum chamber, as the equipment is too large for the vacuum chamber present at the faculty of Aerospace Engineering.

These simplifications are also listed in the literature study. What should be noted is that Leenders used the same simplifications as well, apart from the fact that he did use a lens to concentrate the theater lamp irradiance.

4 Research approach

Now that the thesis goal is set, one can look on towards the practical implications of this objective. How the thesis is going to be undertaken is subject of this section.

The most important notion of the research approach is that the study will be both theoretical and experimental. Theoretical in the sense that the whole thruster design will be based on previous findings in literature and analyses using tools. Practical because the motor will be subject to multiple experiments (see latter section) which will deliver data for validating the tool and assessing the feasibility of the propulsion concept of STP.

The lay-out of the thesis will be discussed in detail in the section containing the work plan. Here, a small path that will be followed is given. First of all, the thruster will be designed. This design needs to adhere to a number of requirements, of which the most prominent are regarding the cost, manufacturability, availability of material and performance. The first three requirements will be further discussed in the section on resources. The thruster will be designed for a thrust around 100 mN (as Leenders had) and the aim is to be in the range of 50-100 seconds for specific impulse. The theoretical performance will be assessed using the tool made in the literature study [30], which is based on tools from Leenders [46] and Preijde [47]. Afterwards, the thruster is produced.

It should be noted that the aforementioned tool is still subject to changes in the thesis. In the literature study [30], a number of recommendations for improvement were given, of which the most notable one was to implement view factors for the RAC, in order to more accurately assess the amount of absorbed irradiance in the wall. For an RAC, the absorbed irradiance determines the thermal efficiency for a large part, so having this more accurate is vital. As was shown in the literature study, the efficiency was on the low side (around 20 percent while percentages of 80 percent are reported), so implementing the view factors will likely give better (higher) estimates.

After the manufacturing phase, the motor will be subject to a number of tests. These tests are thoroughly described in the next section. During the experiments, the motor will hold a number of sensors, which will be monitored using LabVIEW software. The sensors will output the temperature and pressure at various locations, thrust and mass flow of the gaseous nitrogen. This accumulated data will then be used to assess the feasibility of STP and be compared to the theoretical values, in order to validate the developed tool. It should be noted that the tool will also be subject to validation by Leenders' data, consisting of temperature, pressure and thrust readings. This is useful as the data was accumulated under different settings with respect to the upcoming experiments, such as the power and the design of the thruster.

It should be kept in mind that designing and manufacturing the thruster is a time-consuming and costly process. If the thesis proves that not enough time can be allocated, Leenders' thruster, which is still available, can be used for testing. Still, this will only occur when time is running short. Furthermore, if it turns out not to be possible to conduct the experimental phase due to some reason, one should keep an exit strategy. For this thesis it could be to turn the attention towards the STP tool and extend it for multiple configuration types, in order to make it the standard model for STP thruster designing.

5 Experimental approach

As mentioned in the research approach, a large part of the thesis will be the experimental phase. This section will discuss the tests that will be conducted after the manufacturing phase. They are divided into the three subsections found below.

All tests will be done using the following sensors: thermocouples, for measuring the temperature at various locations; pressure sensors, for measuring the propellant pressure at various locations; mass flow sensor, to measure the amount of nitrogen used per second; thrust sensor, to measure the thrust generated when firing the engine. The sensors will be connected to a laptop via National Instrument devices and will be operated using LabVIEW software.

The tests will be done at the laser welding facility located in the faculty of Mechanical, Maritime and Materials Engineering (3mE), DUT. The laser there is capable of emitting a beam of up to 8000 Watts of power, which is more than enough for the experiments, which will be below 1500 Watts of power according to the analysis done in the literature study.

It should be noted that before the first and third test, there will be an irradiance test to assess the outgoing beam power of the welding laser. This will be done using the available PocketMonitor (PMT) 70iCu power meter, that will be positioned under the beam and can measure up to 7000 Watts of power [48].

5.1 RAC (dry) test

The first experiment will be the RAC test. The RAC will be irradiated by the laser without any propellant running. Goal of the experiment is to gather temperature data of the RAC, to see whether the tool accurately predicts the resulting temperature and thermal efficiency of the RAC. For this experiment, only the thermocouples are needed for sensors. The power of the laser output will be varied when thermal equilibrium is reached. For now, equilibrium is defined as the point where the temperature does not change considerably for an amount of time.

5.2 No heating test

The second test will be to let propellant flow through the engine, but without any irradiation. This will be useful to see the effect of non-heated nitrogen on the performance. This will be done in order to validate the performance of the nozzle, without any interference of the heat exchanger.The pressure will be kept at 2 bars (as Leenders did). For this experiment, all sensors as described at the beginning of this section will be utilized. The mass flow will be varied to see the effect of it on the performance, especially the thrust. It is a great way to see if the tool accurately represents the performance and if any assumptions should be reviewed or updated. This test is already described in the test plan in the literature study [30], also containing the experiment design, required materials and safety regulations.

5.3 Full engine test

The third and last test is to run the full engine with propellant flowing while irradiated. This will provide data regarding the performance (thrust, specific impulse), temperature and pressure of the engine and will be key to assess the feasibility of this STP thruster. Throughout the test, the power output of the beam will be altered to see its effects on the performance. As with the second test, it is already described in the test plan in the literature study.

The three tests described above will not necessarily be done at the same time, due to time constraints. If time and the laser welding facility allow, the tests will be performed a second time on a different day, to minimize the risk of the first experiment failing without any data gathered.

6 Resources

This section will provide the reader with an overview of the available resources for the thesis.

The thesis will have to be conducted in the time span of 7 months, which is the equivalent of 42 European Credit Transfer and Accumulation Systems (ECTS) each being 28 hours. It will be done at DUT, faculty of Aerospace Engineering, under the supervision of staff at the department of Space Systems Engineering. There will be minor to no involvement of companies, as DUT houses many faculties and departments having the right resources.

The regular allowance for students is €500,- for the whole duration of the thesis. This is not an exceptionally large fee, which poses constraints on the project (especially with manufacturing and testing). However, many resources can be used free of charge, such as software, the laser welding facility, sensors and so on.

As said in this document before, the relatively low fee will render some options invalid; for instance, not all material choices can be made. Rhenium proved to be an excellent material for RACs due to its high melting point but is very expensive [49, 25]. It is thus ruled out. Another example is the use of tungsten for RACs. It has the same favorable characteristic as rhenium (high melting point), but it has poor machinability [50].

The same applies for the test facilities. Although the welding laser facility is sufficient for testing in terms of power availability, it does not provide any sort of vacuum. There is a vacuum oven present at the faculty of Aerospace Engineering, but it is too small to be of use with the large laser.

It is recommended to team up with fellow thesis students who are in a similar research area, e.g. to see if engines can be used multiple times or to exchange useful information.

7 Work plan

In this section, the work plan and lay-out for the thesis will be given. Please note that the layout is still subject to changes when more knowledge is gained in the starting phases of the thesis.

First of all, the thesis will kick off with the design of STT2.

The design phase will be concurrent to enhancing the STP tool. As was listed in the literature report, it needs to be updated by inputting view factors in the thermal part. Furthermore, care should be taken that the designed motor can be manufactured at DUT (see next section). It should be noted that no effort has yet been directed towards manufacturing; Leenders' engine can be used as a back-up if the building goes awry.

It starts of with the design of the thruster. This will largely be based on theory as taught in the course TRP [51] at DUT and on theory found in literature. The design of the thruster will focus mostly on the

RAC, which is supported by the thermal model that still has to be developed. Furthermore, attention will be given to the nozzle and sensor placement. It is not believed that much improvement can be made in the propellant tank and feeding system.

This data will then, in short, be used for validating the STP tool. For that, the experimental data will be compared to the theoretical data from the equations used to design the thruster. Differences need to be detected and explained. Important questions here are if the thruster performed as predicted and if the required specific impulse, thrust and temperature were reached. With this assessment, conclusions can be drawn whether or not the goal was reached, to prove the feasibility of STT2 and validate the model. Afterwards, recommendations for further improvement in later theses will be given.

The design process will most likely involve multiple iterations to satisfy all requirements at a minimum weight. When the design is satisfactory, the components can be ordered or crafted. This could require a great deal of time, so care should be taken to manufacture the components as soon as possible. The components can then be combined to form the engine.

Then, time will be allocated towards the experiments (see previous section). Test plans should be made, although there is already a test plan available from the literature study. Next to that, all sensors should be collected and checked with LabVIEW.

In the end, after the tests are conducted, the data is analysed. If time permits, a second window for testing a few weeks after would be great, as any faults which might have occurred in the first test phase can be solved. After the validation of the STP tool, conclusions will be drawn and recommendations will be given.

It should be noted that there a few reviews during the thesis which should be adhered to. The reviews will be in accordance with the supervisor and possibly some fellow students and staff. The goal of the reviews will be to receive feedback on the work done and answer any questions the student has. The reviews are listed in the Gantt chart which can be found in Appendix A. The mandatory reviews are the mid-term meeting and the green light meeting (at the end). Apart from those one is advised to hold meetings whenever milestones are reached, such as after the design or before the experiments. In this way, the meetings will also serve as a means of project management, where the student is encouraged to keep up with the schedule he planned himself.

8 Conclusions

This document describes the proposal for demonstrating the feasibility of solar thermal propulsion by improving the design of Solar Thermal Thruster 1 (STT1) in terms of specific impulse. The new thruster will be dubbed Solar Thermal Thruster 2.

STP is a propulsion concept which tops the conventional chemical thrusters in terms of specific impulse. This could reduce the propulsion system mass, which in turn means cost reduction as smaller launchers are needed. Electric propulsion systems do deliver an even higher specific impulse, but they are limited in terms of thrust, which is closely related to the time needed for an orbit transfer or other manoeuvre. STP thus takes the middle ground between these two propulsion types. However, STP has never been flown in space yet.

This heralds the need for a demonstration of the STP concept, to show its feasibility and its unique abilities. This research focuses exactly on that matter, by redesigning the thruster made by Harry Leenders in 2008, as part of his thesis project. The objective will thus be, to demonstrate the feasibility of solar thermal propulsion by improving the design of Solar Thermal Thruster 1 (STT1) in terms of specific impulse. It is decided not to incorporate inflatable concentrators nor fiber optic cables because of time constraints.

In the literature study, various tasks were performed. Knowledge was gained regarding STP and its uses and drawbacks. A tool, named STP tool, based on various models and the course Thermal Rocket Propulsion, was designed in order to predict the performance of an STP thruster. Next to that, a suitable heat source and test bench were sought and found.

In the thesis, the project will be finalized by designing, building and testing STT2, in order to validate the STP tool and demonstrate the feasibility of STP. The aim is to finalize the thesis in March 2020.

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A Appendix A: Gantt chart

Here, the Gantt chart for the final project is depicted.

Figure 2: Gantt chart for the thesis.