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Propulsion System for the European Lunar Lander - Development Status and Breadboarding Activities

Martin Riehle, Thomas Diedrich[2], David Perigo[3], Stephan Kraus, Matthias Bühner
EADS Astrium Space Transportation GmbH; 74215 Moeckmuehl, Germany
[3]ESA ESTEC, Keplerlaan 1, Noordwijk, NL
Contact : Martin.Riehle@astrium.eads.net

Abstract

Within the frame of the ESA led European Lunar Lander program, the propulsion system development has been assigned to Astrium GmbH in Lampoldshausen. Within recent development Phase B1, the propulsion system architecture has been consolidated and refined and initial breadboard testing of essential elements was setup and executed. In addition, key analyses such as thermal and plume interaction of the clustered main thrusters have been performed to further confirm the choosen thruster configuration and architecture.
The paper will describe the major constraints and key elements of the chemical propulsion system (CPS) as well as report some early bread board testing such as :

- Detailed hydraulic characterisation of the liquid side of the feed system. These test results have been used to validate a detailed EcosimPro modelling setup in parallel. The testing and modelling is simulating and covering detailed sequences of the mission to accurately predict i.e. tank residuals.
- Initial hot fire demonstration of an adapted 200N engine being derived from ATV design thruster. The activities and it's conclusions for the consolidated CPS for the Lunar Lander is then being presented.
- Preparations for Helium pressurisation testing with verification of regulator configurations aiming to better manage a stable tank pressure over the large mass flow range.

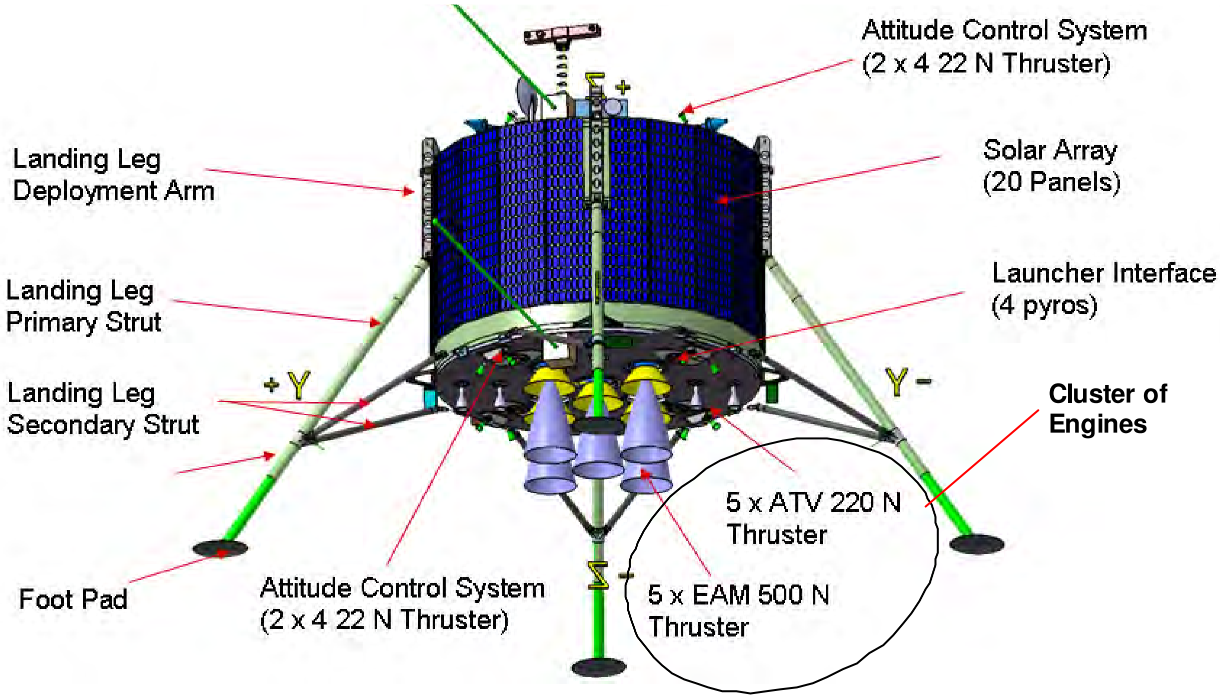

Figure 1: Lunar Lander overall design

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1 Introduction

Within the framework of the ESA exploration roadmap many studies are being underway to outline future missions and concepts. One of the most advanced studies is the European Lunar Lander that targets on the demonstration of a soft landing mission at the south pole of the Moon. Apart from the key objective to deploy scientific payload on the lunar surface, there are many domains in space craft engineering that are assessed to be a new challenge for european space technology. For example all the the features that allow autonomous precision landing and avoidance of hazardous objects. In everey of the classical domains as power, thermal, communication and structure there are many tasks the will push the technologies, knowledge and experience.

2 Lunar Lander CPS

For the propulsion system there are two main decisions taken that drive the overall design and selection of technologies.

First, following detailed mission studies the Lunar Lander shall be a single space craft not being divided in i.e. a lander and an orbiter module.

Second, the propulsion system shall make use from as much as possible available, mature technologies.

These constraints narrows down available propulsion technologies to a set of conventional possible propulsion concepts such as:

- Bipropellant system feeding main and assist engines. With either one large, throttable main engine or a set of clustered engines.
- Dual Mode :Biprop main engine system and distinct monoprop hydrazine system for assist engines.
- Classical Monoprop system
- Advanced Green propellant concepts.

have been compared and assessed within earlier phases of the Lunar Lander studies. Under consideration of availability & TRL and therefore linked to the development effort and risk for some essential elements, **a conventional bi-propellant system with a multi-engine arrangement of 500N main thrusters has been selected as baseline configuration.**

This multi engine configuration allows adjusting the maximum thrust level being required to about >3600 N by a staged activation and deactivation of a set of 500N main engines in steady state mode. Overlaying to the main engines the activation of 220N assist engines at lower thrust level in both steady state and pulse mode then allows to smoothly adjusting any thrust levels [*Figure 2*]. As a result of the choosen thruster configuration any thrust level can be adjusted with an overall vector centered through CoG and simultaneously fulfilling the main ACS vector in parallel. Furthermore, a set of low thrust (22N) ACS engines is being arranged such that fine control for pitch, yaw and roll can be independently be applied in any direction.

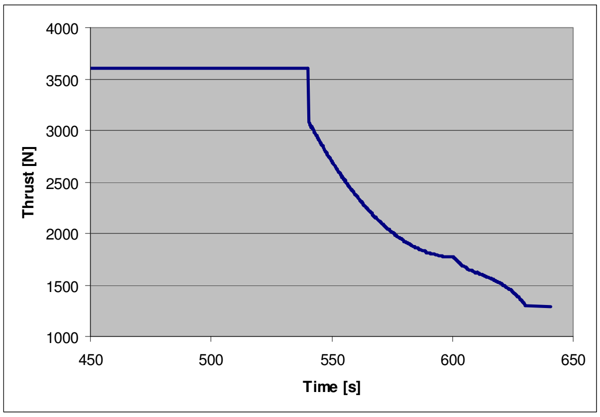

Figure 2: Thrust evolution during Braking and Landing

As a result of the overall spacecraft design with a central avionics bay that allows optimized thermal control power budgeting, the propulsion system and mainly the propellant tanks have to be grouped around this pre-occupied central envelope. Therefore, the CPS layout as being depicted in below [*Figure 3*] is a natural consequence of all the given constraints and requirements to accommodate the tanks, thrusters and other major components.

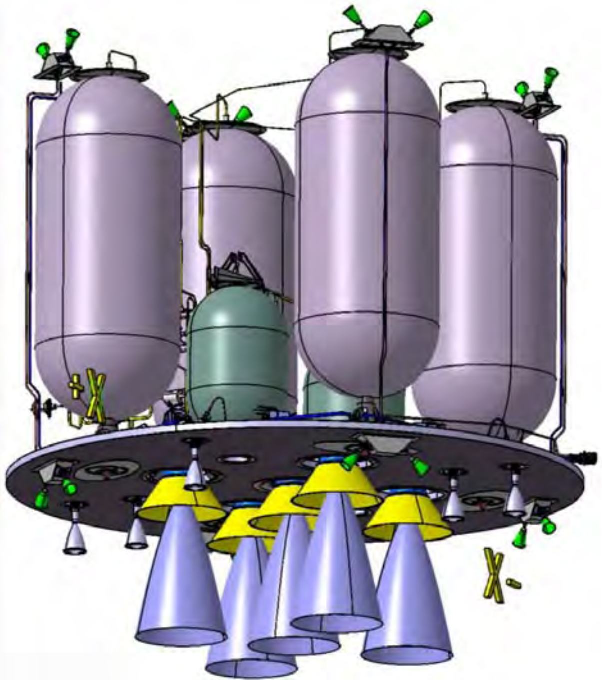

Figure 3: Lunar Lander CPS overall design

The main elements of the CPS are

5 * 500 N Thrusters
6 * 220 N Thrusters [ATV]
16 * 22N Thrusters
2 * 2 * propellant tanks à 370 l.

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2 * Helium tanks à 67 l.
8 * Hi-Flow Latch Valves [ATV]
4 * Helium Latch Valves
2 * Pressure Regulator

+ the standard elements such as pressure transducers, filters, pyro-valves, fill&drain valves etc.
The detailed CPS flow schematics that is being established as baseline for the further Phase B1 studies is shown in *Figure 4*.

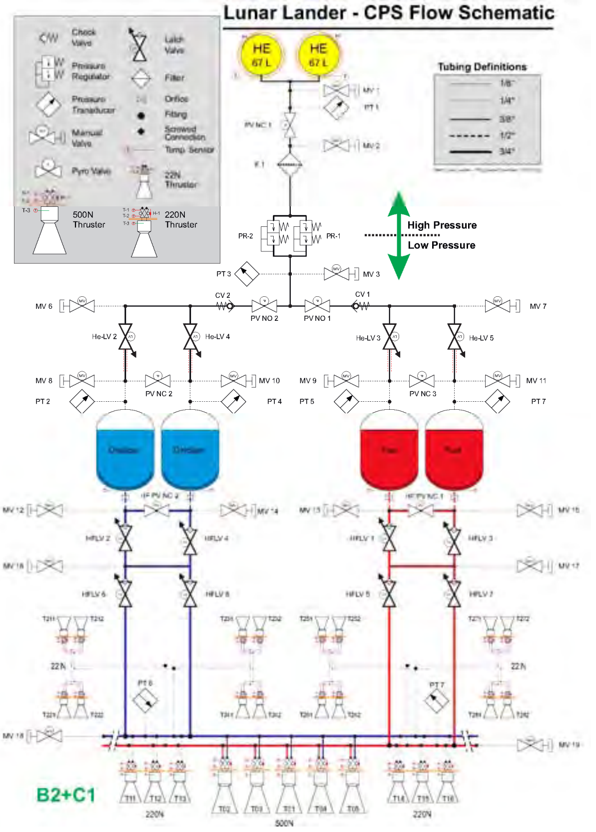

Figure 4: Lunar Lander CPS Flow Schematic

A number of additional criteria and decisions are also taken into account such as.

- 2 inhibits downstream the propellant tanks realized by centralized Hi-flow LVs as pyro-valves of size 3/4" are available off-the-shelf or other units with a low pressure drop at mass flow rates up to 600 cm^3/s. Therfore th use of these ATV LVs allows best control of propellant depletion. In addition this enables on thruster level to use FCV type valves only, as no isolation of main engines from ACS engines is required since all engines are used in parallel during the entire mission. In addition, an isolation of a single 22N by means of a double seat valve is not mandatory due to the relatively short mission duration and potential leak on FCV levels would be tolerated during the active mission phases.

- 1FT design with limited FDIR instrumentation. As many of the components are taken or derived from ATV, the redundancy approach for the CPS is limited to a 1FT concept on the flow paths mainly focussing to the latch valves with the usual exeptions for the tanks, lines etc. For the isolation of the propellant tanks the latch valves on both the Helium side as well as on the propellant side are arranged such that each failure on a single LV could be handled by either a parallel LV or a bypass solution with pyro valves. In addition, each LV is equipped with redundant actuator coils and each PV is equipped with two independent squibs that would both allow a redundancy also on the driver side.

- No large, central propellant filters are foreseen. It has been analysed that as a consequence of the high number of large engines compared with the amount of propellant, the amount of residuals per thruster is quite small and could easily be handeled by the FCV inlet filters. This leads to the elimination of a contributor of significant pressure drop and residuals.

3 Lunar Lander Components

In the following the selection of the main components is presented on basis of some key selection criteria such as availability, accessibility and suitability for the mission. In addition, an all-european approach sall be applied whenever possible not only for the engines but also on all other CPS components and elements in order to foster european technologies and suppliers.

Figure 5: 500N main engine.

500N thruster

As no single throttable central engine is available that would fit into the system, the high performance European Apogee Motor (EAM) aiming at an ISP of >323 s have been selected for the main manoeu-

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vers. This engine is currently un-der development at Astrium and has successfully passed PDR with the configuration shown in *Figure 5*. So far, the key performance requirements have been met. According to planning, the engine will reach CDR state in late 2012 and would therefore fit into the overall project planning. In addition, alternatives options with established engines would be available to safeguard this main component.

220 N Assist Engine

For assist orbit manoeuvres and to support the main engines the 220 N engine being qualified for the ATV attitude control has been selected. This engine is characterised by a wide operational range in both steady state and pulse mode firing. The thruster is designed for a thrust level of 220 N and a specific impulse Isp > 280 s at nominal inlet conditions of 17 bar. For an application on Lunar Lander the thruster needs to be adapted w.r.t. reduced inlet pressures. In addition, AOCS requires the engine to cope with a frequency of 2.5 Hz deviating from the qualified domain of 1Hz.

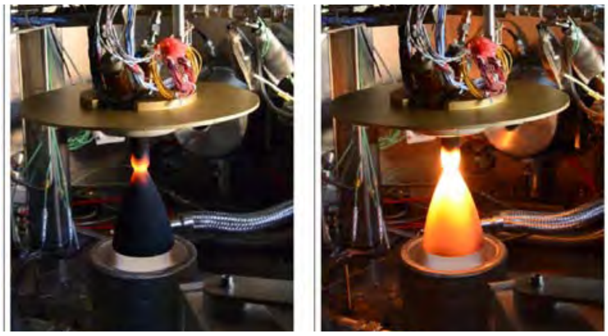

Figure 6: 220 N assisst engine.

The 220 N Thruster currently at TRL 9 in it's baseline ATV configuration is assessed to be at TRL 7 w.r.t. the needs to Lunar Lander. This is now confirmed by the bread board testing described in this paper as well as presented in full detail in [Ref. 2]. These early bread board demonstrations have been performed to determine the detailed characteristics under the specific Lunar Lander environment and to safeguard the thruster selection in an early stage as no real backup or alternative would be available in this thrust range with the multitude of SSF & PMF capabilities.

22 N ACS Engine

For Attitude Control, a 22 N thruster is being required as initial AOCS analysis confirmed that a 10 N thruster would not be suitable. In addition, the flow control valve will be a single seated FCV configuration as a result of the overall inhibit concept of the CPS (see above). As primary option the Astrium 22 N thruster has been selected. As the ACS thrusters are mainly operating in pulse mode the steady state performance and the total throughput are less demanding compared with typical application on Comsat, the design and verification approach could eventually be simplified. The Astrium 22 N engine offers an excellent baseline w.r.t. envelope and performance being demonstrated during earlier development and pre-qualification. The performance of the Astrium 22N thruster has recently been re-demonstrated under consideration of specific Lunar Lander mission activation profiles and with an all-european configuration. Details are presented in [Ref. 3]. Even in worst case duty cycle, there is tremendous thermal margin on the combustion chamber. The thruster is currently at TRL 6 and the FCV at TRL 8 - ready for a dedicated final project qualification.

Figure 7: 22 N ACS engine.

Alternative thrusters have been assessed in detail. Any alternative the the Astriuim all-european baseline engine would be subject to export control restrictions and would also need a final mission oriented adaptation of design to a single seat valve configuration and a dedicated delta qualification effort.

Propellant Tanks

Following a detailed trade-off, a concept and layout for the propellant tank and PMD have been baselined being derived from a Eurostar 3000 design for the tank shell and from ATV for the PMD. In particular, the tank shell needs to be adapted to comply with the structural requirements from a launch with Sojuz. Complementary, the PMD design and outlet ports have to be adapted to take into account flow rates of up to 300 cm³/s per tank. So far, the trajectory analysis indicates very low disturbances and accelerations that could excite sloshing which would then require improved anti-sloshing devices. As assessments show that the mass of the PMDs and therefore the residuals are driven by the requirement for maximum mass flow rates, a staged thruster activation allowing propellant settling prior to go to full thrust was then being set as baseline for the main delta-V maneuvers. This then results in a supporting acceleration for pre-orientation of propellants and minimizes the PMD design w.r.t.

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mass and residuals. When entering the next phase of the Lunar Lander project, a detailed development and verification plan will be executed based on the findings and definitions from Phase B1.

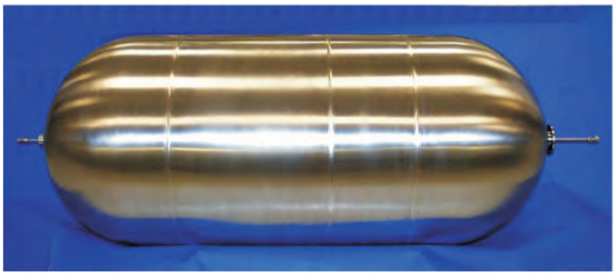

Figure 8: Eurostar 3000 based propellant tank.

Helium Pressure Regulator

Standard type pressure regulators are foreseen for application in the Helium pressurization system. Linked to the high flow rates of up to 1.2 kg/s out of the relatively small propellant tanks an according He mass flow of up to 3 g/s is being required. As of now, a configuration with 2 parallel regulators and one single check valve (CV) per branch is choosen. Nevertheless, the tank pressure would still massively drop during the main mission phases when maximum thrust hence mass flow is commanded. The pressure would evolve from about 18 bar down to < 17.5 bar as shown in *Figure 9*.

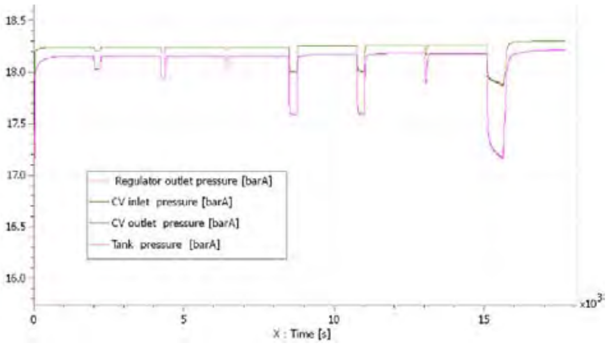

Figure 9: Evolution of Helium pressures over mission.

Accordingly, the pressure drop is amplified on the liquid side. Consequently, the variation of thruster performance due to variation of the inlet conditions is much more than experienced on a typical Comsat and has to be analysed in full detail. Therefore, a detailed bread board testing and performance modelling have been planned and executed in this Phase B1 of the project. The results and status of the breadboarding is presented hereafter.

Further CPS Components and Elements

Beyond the key elements presented above, the CPS layout and the choosen components are quite conventional and follow the COTS and heritage approach as much as possible in order to limits the number of critical items to be emphasized during a further development.

4 220 N Bread Board Hot-Firing

Being somehow unique due to its thrust class and performance characteristics, the 200N class engine has been developped and qualified for ACT/BKT on ATV. This engine has been identified to be suitable as assisst engine in support of the 500N main engines. As there is no backup or alternative for this class of compact and engine being able to performa SSF as well as PMF in a wide range of operational envelope, the suitability had to be verified in an early stage of the project in order to safeguard the overall thruster concept and GNC strategy. For this purpose a detailed breadboard hot firing campaign have been setup to validate, confirm and refine the assumptions taken in the various models.

Starting for an ATV type engine definition and test requirements, the main differences are:

- reduced reference inlet pressure of 15.5 bar as well as low overall inlet pressure domain.
- low propellant reference temperature T=5℃.
- increased pulsing frequency up to 3 Hz
- High amount of crosstalk and disturbance expected from the total of up to 11 large size thrusters being in operation during main thruster phases.

To validate the above stated requirements, a hot firing campaing was performed with a focus on thermal bahaviour in pulsed mode and Impulse Bit repeatability at higher operating frequencies.

Apart from steady state and pulsed mode performance mapping, simulated braking, descent and landing maneuver based on current GNC data was performed.

Some of the test results of the hot firing campaign are presented herafter. The full set of details on this test campaign and evolutions of the 200N class thruster is given in [Ref.2].

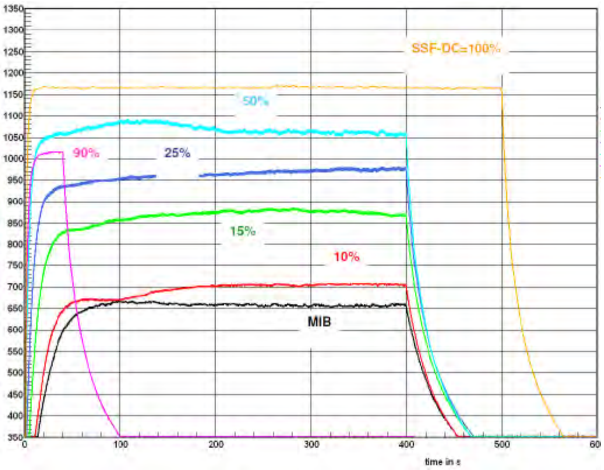

Figure 10: Throat temperatures for 2.5 Hz

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As an example, the above Figure 10 illustrates the thruster throat temperatures at a pulse frequency of 2.5 Hz that is selected for GNC. As can be seen, the engine stabilizes well at all duty cycles and for pulse frequencies up to 3Hz. Here also the self induced hydraulic disturbances are increasing with frequency and the robust engine behavior is demonstrated. During all SSF & PMF firings, the thruster behaved very well at all frequencies with no indications for any combustion or thermal instability.

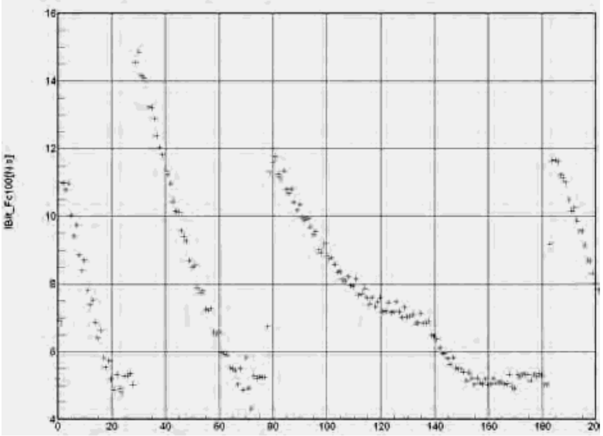

Figure 11: Impulse bits during descent & landing.

First and foremost the lunar landing & descent maneuver demonstration responded with moderate temperatures and smooth overall behaviour. At the end, it could be summarized that the man-rated Astrium ATV 220N thruster's performance showed an excellent suitability for the Lunar Lander mission. There is no indication for blocking points requiring any design change on the baseline thruster other than the proper selection of the trimming orifices due to a lower standard operation pressures compared with ATV. In addition, the engine could be simplified by reducing the flight instrumentation as no 2FT will be required with the simpler FDIR approach.

On the further roadmap of the Lunar Lander program it is recommended to perform an integrated "PQM" type hot firing campaign with a representative set of main and assist engines in order to finally validate the individual models built for the CPS characterisation.

5 Hydraulic Bread Board Test

For the analysis of the complex Lunar Lander propulsion feed system a detailed model has been established with EcosimPro. Within the frame of the validation of the EcosimPro Model a hydraulic bread board test was defined and setup was implemented such that analytical model can be validated in detail in static and transient conditions.

The hydraulic bread board test setup as schematically depicted in *Figure 12* is only an extraction of the propulsion system but represents the flight configuration as much as possible. Some changes to the breadboard test setup are necessary due to instrumentation, facility and other constraints.

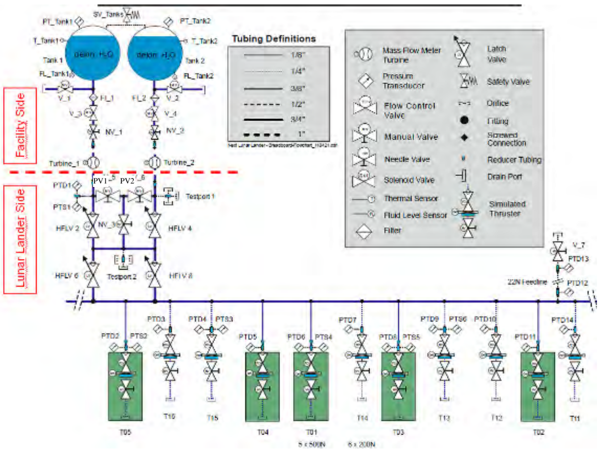

Figure 12: Hydraulic bread board setup schematic.

First, only the oxidizer side of the CPS is considered for this examination whereas the Fuel side is as symmetric and would not make much difference in water testing. The feed lines are fully representative w.r.t. size, length, bending, fitting, welds etc. The latch valve as the central elements in the liquid branch of the feed system inbetween the tanks and the annular distribution ring are fully representative units taken from former ATV tests.

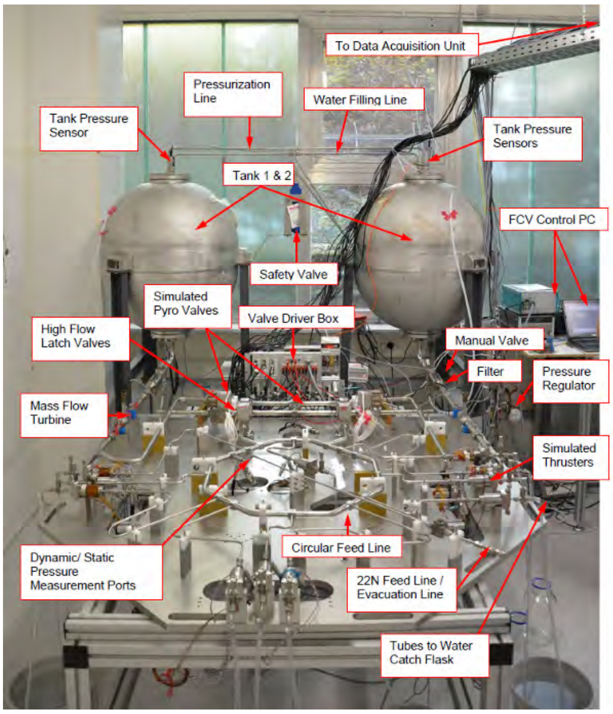

Figure 13: Hydraulic bread board setup.

The 500N and 220N Thrusters are both modelled by a flight type FCV's combined with real thruster

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trimming orifices and a downstream valves that is fine tuned such to represent the pressure drop and flow resistance in static conditon of a thruster firing. Each 'simulated thruster have been assembled and fine tuned vs. hot fire test data prior to installation to the overall bread board setup. The 22N thrusters are not considered in detail and only one long supply line feeding a pair of ACS engines is modelled. As the low fuel consumption and the strong decoupling effect of their relativley long feed lines the influence on the inlet conditions and cross coupling is negligible.

The primary test objectives of this hydraulic bread board test are the flow characteristics of the liquid side of the lunar lander propulsion system as well as the symmetry of tank expulsion. In order to get test results for this hydraulic bread board test that facilitates the validation of the analytic model, the influence of the tank pressurization system has to be minimized by keeping the tank pressure as stable as possible. This has been performed by integrating an industrial pressure regulator in combination with a bang bang type electonic pressure regulator. Based on these experience the test setup is lateron being upgraded and extended to also cover the gas side of the CPSand is presented in the next chapter.

The following main characteristics are examined:

- Priming of the system and peak pressures.
- Pressure drop in the system at different mass flow rates.
- Water hammer in the system at different operation cycles of the "simulated thrusters"
- Cross talk of the thrusters at different possible sequences and one flight representative sequence
- Examination of Latch Valve failure cases for all the previous examinations
  - Failure Case 1:
    HFLV4 closed / PV2 open
  - Failure Case 2:
    HFLV8 closed

In order to accomplish the validation of the Hydraulic simulation model, the test campaign was divided into two major sections:

Static Pressure Drop Evaluation

For the test data evaluation the pressure along the feed lines from the tanks to the thrusters is examined. Therefore, the propulsion system is divided in the five sections tank, feed line, bypass, circular feed line and thrusters [see *Figure 14*]. In each section pressure transducers are implemented in the tubing such to allow undisturbed measurement. In the thruster section pressure sensors are integrated at the inlet of selected Thrusters (T03, T05, T11, T12 and T15).

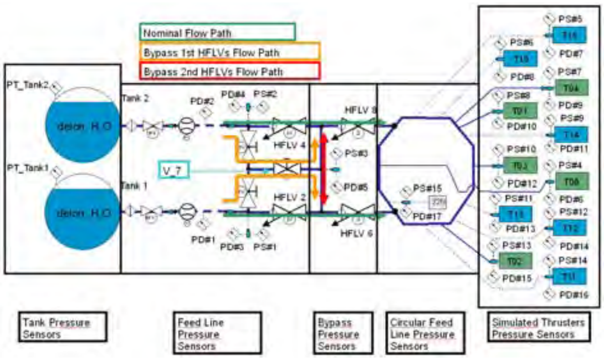

Figure 14: Definition of flow paths sub-divisions.

The test data evaluation of the static hydraulic bread board pressure drop measurement tests confirms a highly symmteric characteristic of the liquid side of the feed system design.

- Even without detailed pre-trimming of the individual branches the pressure drop for all branches including the bypass flow paths show only minimum variation within the measurement accuracy. Only the bypass paths of each branch showed a minimal offset in a 1FT scenario. The necessary pressure drop adaption in the bypass flow path was easily performed with the adjustment of manual valves representing / simulating the by-pass pyro valves.

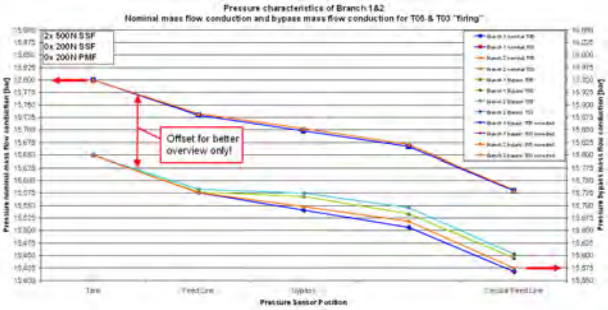

Figure 15: Static pressure drop along the fow paths

- The evaluation of the test data confirms that the pressure differences all around inside the circular feed line are negligible. There are only minor differences in the inlet pressures of the thrusters between the nearest and the most extreme positions. Therefore the propellant supply of the 200N and 500N thrusters is equally distributed regardless of their position on the circular feed line. The equal propellant supply of each thruster was also demonstrated for the latch valve failure case evaluations. Neither case had a negative influence on the homogenity of thruster inlet conditions.
- The overall pressure drop from the tanks to the inlet of a "firing" thruster is ~510mbar for the maximum mass flow (5x 500N & 6x200N firing) and ~140mbar for the minimum mass flow (2x500N firing) being depicted in *Figure 15*. This results in a maximum thruster inlet pressure dif-

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ference of ~270mbar for the nominal flow path between the maximum and the minimum mass flow case.

- For failure case 2 the whole mass flow from both feed branches has to pass through one Latch Valve into the circular feed line. This results in an increase of the overall pressure drop of ~835 mbar for the maximum mass flow and ~150 mbar for the minimum mass flow.
- As the thrusters do not have a perfectly symmetric distribution along the circular feed line, there is a slight difference of ~1,5 g/s at mas flow rates in the purging of the tanks. This however is only the case if only non-symmetrically distributed thrusters are fired. During the "firing" of only symmetrical distributed thrusters the tanks are equally purged and the mass flows of both feed branches match each other for the nominal flow paths.
- For the Failure Case 2 the circular line is fed by one Latch Valve only. Due to this specific flow path the mass draininig from one tank is preferred. Leading to a difference of up to ~8 g/s in worst case.

	Nominal Flow Path		Failure Case 1		Failure Case 2	
	All Thrusters firing		All Thrusters firing		All Thrusters firing	
	Branch 1	Branch 2	Branch 1	Branch 2	Branch 1	Branch 2
Sensor	MFT1	MFT2	MFT1	MFT2	MFT1	MFT2
Relation	<		>		>	
Δ Mass Flow	~1,5 g/s		~3 g/s		~8 g/s	

Based on even these initial test results, the excellent symmetry of the pressure drop characteristics can be stated leading to almost perfect draining of the tanks in all nominal thruster firing conditions. For off-nomnial failure cases, the small non-symmetries can be optimized by further design studies based on the fully validated analytical modell.

Validation of Static Model

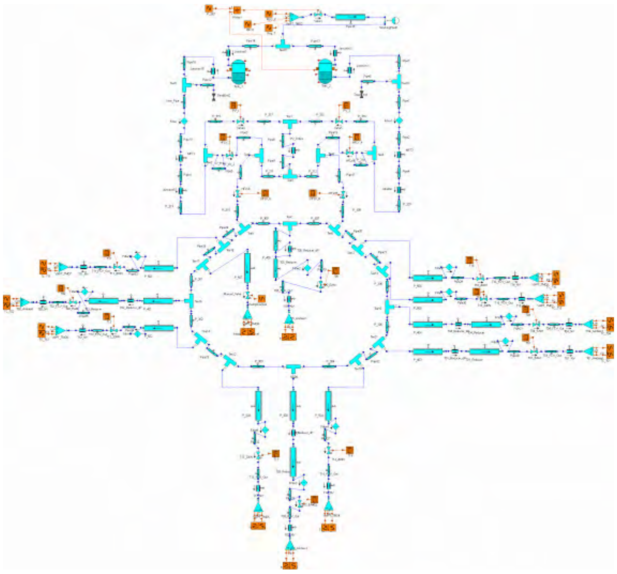

Figure 16: Layout of EcosimPro model.

According to the bread board test setup CAD-data the following EcosimPro model have been established and then validated step by step.

- Due to the complexity of such a simulation model the generation and validation of the EcosimPro Model was separated into different parts. First of all the simulation models of single components, measured on individual sub-setups, have been validated. The retrieved data from these models were then integrated step by step into the overall simulation model of the hydraulic breadboard test setup. As another intermediate step each single thruster integrated into the bread board test setup was pre-validated.

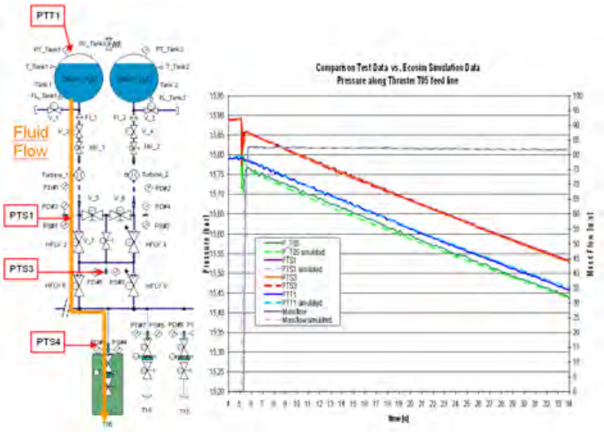

Figure 17: Comparison of measurement with simulation on nominal flow path of T05.

Finally, the validation of the entire model was performed using all the different thruster firing sequences and the latch valve failure cases. The following plots show the comparison of test and simulation data for the first part of the pressure drop measurement sequence. The plots are separated into mass flow, pressure from tanks to the circular feed line, pressure at the 200N thruster inlets and pressure at the 500N thruster inlets.

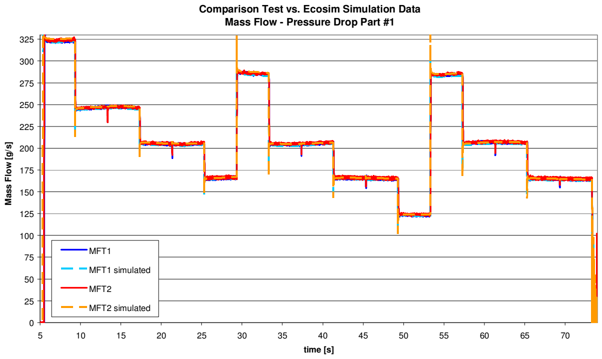

Figure 18: Comparison of measurement with simulation for mass flow rates.

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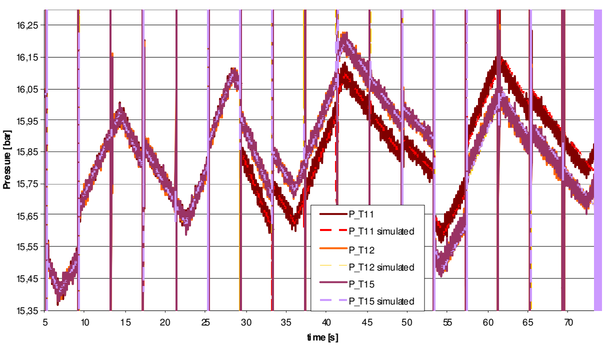

Figure 19: Comparison of measurement with simulation for assist engines mixed operation.

- The simulation model shows a good overall matching to the measured data. Due to some simplifying assumptions for the simulation model a small divergence of the data builds up after ~55 s continuous testing. Part of the divergence can be tracked back to the small variation in the regulator set points but can be compensated in later testing and validation. This behavior of the simulation model can be identified systematically for most pressure drop measurement parts including the latch valve failure cases. The behavior is however manageable and being considered for the further improvements of this simulation model.

Summary

Generally speaking the Lunar Lander hydraulic bread board test confirms the mature overall design of the feed system design. Only minor final adjustments in the feed system design will be necessary. Also the overall adjustment of the EcosimPro Model is good for all thruster sequences and latch valve failure cases and can be used for the further investigation and optimization.

Ongoing Work

For further comprehensive and detailed modelling of the Lunar Lander Propulsion System additional testing are deemed necessary. First of all the transient pressure characteristics have to be evaluated in more detail and the transient EcosimPro Model fine-tuned accordingly. Due to the complex process of accurate transient pressure modelling and simulation, this ongoing validation is being performed using high resolution thus time consuming simulation modeling. The initial results are very promising and are well in line with the test results over a wide operational range.

6 Helium Pressure Regulator integrated Bread Board

As a next step in improving and extending the overall EcosimPro modelling, the flight like pressurization system will be implemeneted. Both into the simulation but also into the bread board setup that will then grow to a full scale test bed for gas and liquid side of the CPS and will allow a coupled testing. As the Helium Regulator bread board was originally planned as stand alone, it is now planned to establish the combined test bed and environment by an massive and complete extention of the existing hydraulic setup as shown in *Figure 20*. The better access to an inhouse test setup would open the possibility to test any pressure regulator configuration under more flight like conditions.

Due to the demand of Helium flow and required regulated pressure characteristic, the function of the Pressure Control Assemblies can not be realised with a typical PCA layout know from i.e.Comsats. The flow demand of 3g/s and up to 4g/s GHe requires either a new Pressure Regulator component or, as shown in *Figure 4* the combination of known components to a parallel operation such as using the PRs being qualified for ATV. In addition, two CVs contribute their cracking pressure and delta P to the overall regulation charcteristic.

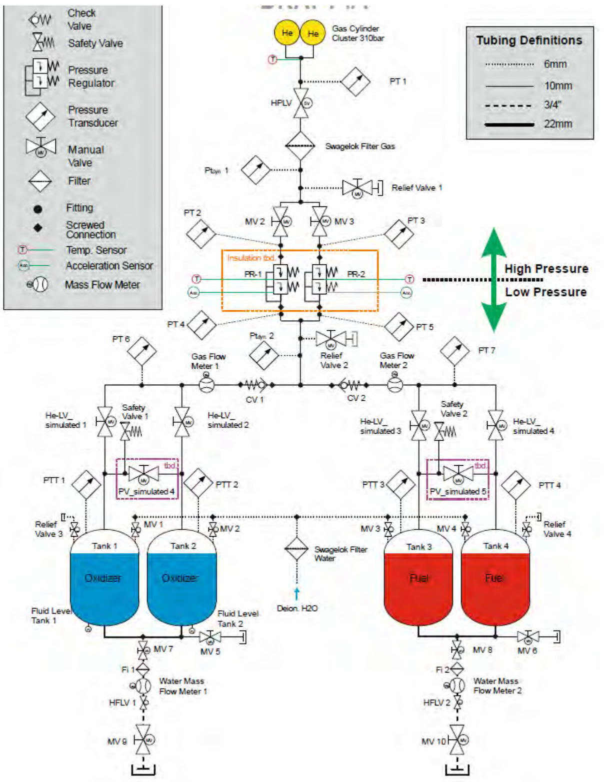

Figure 20: Layout for Helium regulator bread board testing.

The set of test objectives below is defined for PCA performance investigation within the frame of the planned bread board testing, such as:

- Regulator characteristics at mass flow rates up to 3 g/s and at minimum temperatures.
- Regulator characteristics at priming phase, when operating with/without flow limiter.

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- Helium feed system characteristics with either single Check-Valve or double-parallel Check-Valve configuration.
- PCA regulated pressure and Lock Up at PT3 for:
  - Inlet pressure and GHe flow variation with:
  - identical PR adjustment (ideal case)
  - different PR adjustment resulting in imbalanced Helium flow through parallel PR
  - imbalanced delta P in one single downstream branch
  - slam start investigation

As of today, the extended bread board test campaign described above is in preparation and will significantly enhance the level of accuracy of the modelling prediction and which will finally lead to an improvement of the CPS design, reduction of residuals and ultimatly to an increase of payload.

7 Clustered Thruster Concept

As a consequence of selecting a clustered concept for the main and assist engines some effects usually not known on CPS with a single main engine have to be considered.

First, the thermal radiation interchange in particular between the main engines could lead to exceeding given qual limits which would then eventually neccessitate to reduce the operational conditions for the engines then resulting in an undesirable loss of performance. Therefore, a detailed thermal analysis using a validated thermal model of a single main engine have been established as shown in *Figure 21*. The results are quite promising as the increase in temperatures are surprisingly low as reported in *Figure 22*. This can be explained by the fact that >90% of the energy is radiated off by a relatively small area at the nozzle throat and despite the engines are quite close to each other, the reduction of view factors for these hot areas is very small. Consequently, this effect of a clustered concept is of no concern for the given configuration.

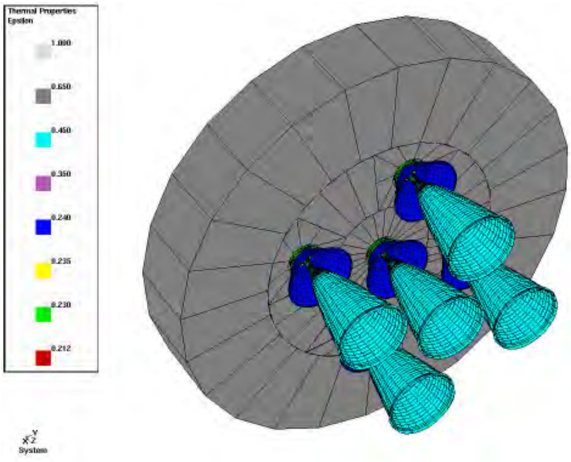

Figure 21: Thermal interaction of main engines.

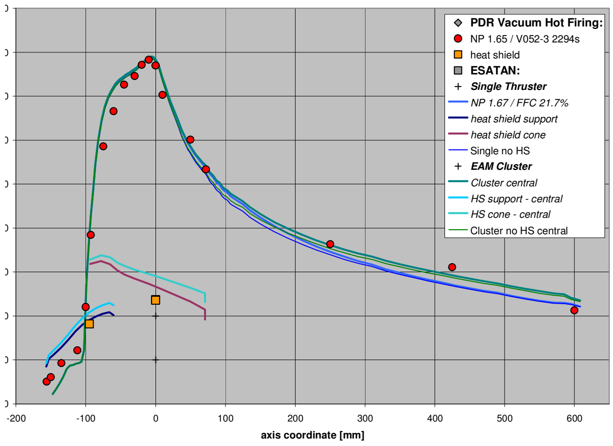

Figure 22: Thruster axial temperature distribution due to thermal interaction of main engines.

Secondly, the interaction of the multiple plumes result in some effects that are not a simple superposition of single plumes. Enforced backflow due to plume-plume interactions in particular in a 3D configuration is expected to increase of heat flux to the spacecraft but also to parasitic thrust that may be of a magnitiude of up to 1-2 % that needs to be considered in the budgeting. 3D modelling and subscale validation testing is being foressen within the further course of Phase B1 of the Lunar Lander program.

8 Acknowledgments

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