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SCALISS: A European tool for automated SCAling of LIfe Support Systems

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Designing the Environmental Control and Life Support System (ECLSS) for exploration missions to the interplanetary space is a complex task beginning from the definition of the needs (e.g. diet, safety, radiation level,..) up to the selection of technology possibilities. In this context a major issue is the influence of crew number and mission duration to the ECLSS design. These are the main reasons why during mission studies the design of the ECLSS system mostly starts from scratch. Uncertainties about requirements, functions and technologies most suitable for the mission lead to a high number of iterations before a baseline design can be achieved. The aim of the SCALISS (Scaling of Life Support Systems) study was to understand and investigate in ECLSS functionality, technologies and scalabilities in order to produce a robust initial design starting point for future Phase-A studies with an automated tool. The developed Java-based ECLSS sizing tool is described in this paper together with the validation case study results. The possible evolutions and interactions with the ALiSSE tool are also described.

Nomenclature

ALISSE	=	Advanced Life Support System Evaluator
ALSSAT	=	Advanced Life Support Sizing Analysis Tool
CEF	=	Concurrent Engineering Facility
DLR	=	Deutsches Zentrum für Luft- und Raumfahrt
ECLSS	=	Environmental Control and Life Support System
EVA	=	Extra Vehicular Activity
GUI	=	Graphical User Interface
LDSS	=	Lunar Destination Surface System
LEO	=	Low Earth Orbit
MDAL	=	Mars Descent-Ascent Lander
MTOM	=	Man Tended Orbital Module
MSHL	=	Mars Surface Habitat Lander

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MTV	=	Mars Transit Vehicle
NEA	=	Near Earth Asteroid
SCALISS	=	Scaling of Life Support Systems
SEV	=	Space Exploration Vehicle
TASI	=	Thales Alenia Space Italia
TRL	=	Technology Readiness Level

I. Introduction

DESIGN of a safe, resources affordable and high performing Environmental Control and Life Support System (ECLSS) is a considerable challenge for space exploration, due mainly to the many multidisciplinary aspects which need to be faced and to the high number of variables involved. Loop closure degree, technology choices, buffer sizes, subsystems' flow rate, redundancy and waste handling strategies, all need to be determined in order to design an appropriate and optimal system, providing proper environmental conditions, supplying required resources and removing or recycling wastes. The number of variables which need to be considered opens up a huge amount of design choices to be performed, critical in particular in the early phases of a project.

In this framework, the aim of the SCALISS study was to understand and investigate in ECLSS functionality, technologies and scalabilities in order to produce a robust initial design starting point for future Phase-A studies. This included a comprehensive review of technology, functions and ECLSS systems. The main outcome of the study is the implementation of the ECLSS linear scaling methodology developed into an **automated tool**. This tool is called **SCALISS**. The detailed objectives of the study were the following:

- to address human missions (e.g. planetary/low orbit base, transit mission, etc.) to all destinations of interest including LEO, CIS-Lunar space and interplanetary space (e.g. Mars, asteroid, etc.), in order to define a set of relevant scenarios (for missions with duration of up to 600 days and a crew of up to 6 astronauts)
- to perform a comprehensive review of the different functions and necessary technologies of an ECLSS system, including an extensive review of the theoretical functioning and available technical solutions, even at the current low TRL solutions
- to set the foundation for a reasonable sizing of the major ECLSS parameters (mass and power in this first iteration of the tool) for generic missions, based on the review of point 1
- to develop a model, related to functions and technologies to scale ECLSS regarding crew number and mission duration as a minimum. This model had to allow a Phase-A assessment for the ECLSS in the context of a future mission design.
- to implement the elaborated model into a preliminary Java-based automated tool, to be validated on a set of 6 mission scenarios

This paper briefly summarizes the work done in support to the generation of the current version of SCALISS, then focuses on the description of the current capabilities of the Tool.

II. Selection of technologies covered by SCALISS (build 1.3.170302)

The list of technologies implemented into the current version of the tool was derived with the following logic:

- Identify 6 relevant scenarios for validation of the tool covering destinations of interest for exploration including LEO, CIS-Lunar space and interplanetary space, for missions with duration of up to 600 days and a crew of up to 6 astronauts
- Identify the functional architectures linked to each selected scenario
- Identify an initial set of technologies capable of fulfilling the functions emerged in the functional architectures study

A. Reference scenarios selection

Before reporting the selected scenarios, the understanding of what was considered a "scenario" needs to be shared. Each scenario needed to be detailed enough to support the ECLSS scaling exercise by highlighting all the major parameters impacting the design, thus a list of the most significant overall mission parameters describing it was identified, as provided in Table 1. Specifically, these values quantify, in addition to the crew size and the mission segment duration specifically subject of this study, also habitat and atmosphere main characteristics, nominal mission-specific crew inputs, as well as extra-vehicular activity (EVA) requirements.

Relevance of a scenario was then defined based on:

- Contribution of the scenario in covering the ECLSS scaling exercise crew size and mission duration ranges (as well as different mission profiles)
- Likelihood of the scenario with respect to ESA applicable exploration roadmap
- Missions to LEO, NEA, Moon and Mars
- Orbiting facilities as well as surface access/mobility and transit habitats
- Crew size from 2 to 6 crew members
- Missions with duration from 6 to 600 days
- Missions including EVA

Table 1: Scenario Definition Parameters List

Parameter Type	Parameter
Mission Definition	• Destination (e.g. Mars Surface, LEO) • Number of crew-members • Manned mission duration • Number of modules re-pressurization per mission • Inclusion of contingency considerations • Energy source
Vehicle Definition Parameters	• Number of Modules • Maximum Atmospheric Leakage per Module • Total Pressurized Atmospheric Volume
Interior Atmosphere Definition (Manned)	• Nominal Total Atmosphere Pressure • Nominal Atmosphere Oxygen Partial Pressure
Driving Nominal Crew Inputs	• Water (Drinking, Oral Hygiene, Hand/Face Wash, Urinal Flush, Laundry, Shower, Dishwashing) and food (incl. water content)
External Interfaces, EVA Support	• Total Number of EVAs per Mission • Crew-members per EVA • EVA Duration • Airlock Free Gas Volume • Airlock Gas Losses % per Cycle

Based on the presented considerations, the exploration scenarios selected for further reference of SCALISS study activities are the following:

- Space Exploration Vehicle[1] (SEV)-like system: 2 crew members, 14 days mission, Moon gravity, no EVA
- Man Tended Orbital Module[2] (MTOM)-like system: 4 crew members, 14 days mission, µg, no EVA
- Mard Descent-Ascent Lander[3] (MDAL)-like system: 6 crew members, 30 days mission, µg EVA
- Lunar Destination Surface System[3] (LDSS)-like system: 4 crew members, 98 days mission, Moon, EVA
- Mars Transit Vehicle[3] (MTV)-like system: 6 crew members, 360 days mission, µg no EVA
- Mars Surface Habitat Lander[3] (MSHL)-like system: 6 crew members, 600 days mission, Mars, EVA

Table 2: Selected scenarios main data table

	SEV	MTOM	LDSS	MDAL	MTV	MSHL
Crew Size [CM]	2	4	4	6	6	6
Miss. Duration [days]	14	14	98	30	360	600
Destination	Flexible, incl. NEA and Mars	Cis-Lunar environ. (µg)	Lunar Surface	Mars Surface/ (µg)	Mars transit (µg)	Mars Surface
EVA Presence	Flexible	No	Yes	Yes	No	Yes
Airlock Presence	Flexible	No	Yes	Yes	No	Yes
Included in GER	Yes	Yes	No	No	No	No
ECLSS Design Data Available	Poor	Poor	Yes [3]	Yes [3]	Yes [3]	Yes [3]
Pressurized Volume [m^3]	-	-	39.6	25.5	110	110
Water Input [kg/CM-day]	-	-	6	7	22	22

B. Functional architectures selection

For each scenario the proposed functions were combined to form an ECLSS functional architecture. Each architecture shows the interrelationships between the functions as well as mass and data flows. These activities were carried out with a concurrent engineering workshop at the Concurrent Engineering Facility (CEF) at the DLR site in Bremen, Germany. The functional architectures for all mission scenarios have commonalities, but can be divided into two groups, as shown in Table 3. SEV and MDAL form a group of scenarios using non-regenerative air and water management. MTOM also does not use regenerative functions for the air management, but utilizes condensate water recovery to regenerate some water. LDSS, MTV and MSHL include regenerative functions for these domains. The MSHL scenario incorporates the largest amount of functions also including food production, waste recycling and biomass production, which are not used in the other scenarios.

Figure 1. Concurrent Engineering session at DLR bremen.

The different groups result mainly from the differences in the mission durations. Hereby, the LDSS scenario is the border between using regenerative and non-regenerative methods. During the CE-Workshop all participants agreed, that the LDSS scenario requires regenerative functions, although future progression of the study may prove a different result. Other factors such as crew size, number of EVAs and number of modules have little to no effect on functional level, but may affect the technology choices in the following versions of the tool.

However, it is important to highlight that not all the results of the selected functional architectures are dictated by engineering evaluations of convenience for including or not a function (e.g. for regenerative technologies-related functions). The need of some function was introduced to provide a broader set of case studies for the ECLSS scaling rules validation phase, as for example done for the biomass production capability considered within the MSHL scenario.

Table 3: Commonalities in ECLSS domains among the six mission scenarios

	EVA Support	Air	Food	Water	Waste	Biomass	Thermal
SEV	Y (no IVA)	non-regenerative	Y	non-regenerative	Y	N	Y
MTOM	Y	non-regenerative	Y	regenerative (only condensate water)	Y	N	Y
LDSS	Y	regenerative	Y	regenerative	Y	N	Y
MTV	N	regenerative	Y	regenerative	Y	N	Y
MDAL	Y	non-regenerative	Y	non-regenerative	Y	N	Y
MSHL	Y	regenerative	Y (incl. production)	regenerative	Y (incl. recycling)	Y	Y

C. SCALISS ECLSS Technologies List

A technological architecture was associated to each scenario identified functional architecture. The following possible technology to function relation configurations were identified:

A. Bi-univocal relation between a function and the technology (or set of technologies) capable of covering such function

B. The same technology is capable of performing/collaborating to multiple functions (e.g. an ISS Major Constituents Analyzer covers both O_2 and CO_2 partial pressure monitoring)
C. More technologies are available to cover the same function (e.g. carbon dioxide removal can be performed with LiOH canisters, 4BMS, SAWD, EDC, etc.)
D. Some of the selected technologies that perform multiple functions offer redundancy with respect to a function (i.e. a crop growth chamber, chosen to cover food production, concurs also to atmosphere revitalization, in partial superimposition with a carbon dioxide removal system)

Both high and low TRL technologies were considered and compared based on a logic not reported within this paper. The typical result obtained for each scenario is reported in Figure 2. The complete list of technologies covered by current version of SCALISS is reported in Appendix (Table 4).

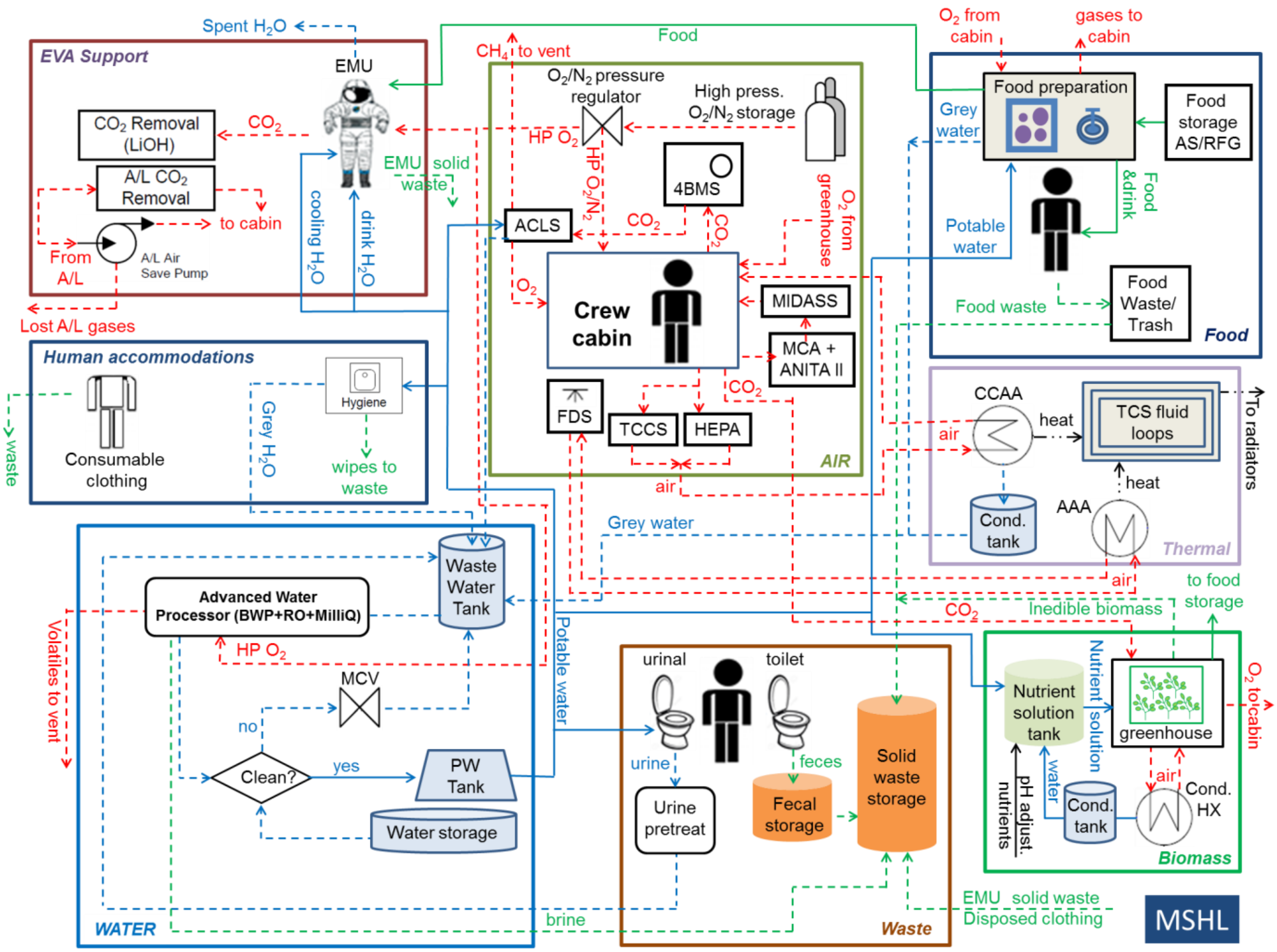

Figure 2. Technological architecture schematic for Mars Surface Habitat Lander.

III. SCALISS Tool Description

SCALISS Tool is a stand-alone Java application that permits to open “SCALISS “projects. It uses the “Wizard” model to handle the interaction with the user. SCALISS projects are modeling of complex systems divided into domains and within which are present subsystems composed by technologies. These technologies can be implemented by different mathematical models (summarized in formulas). The implementations of the SCALISS technologies use mission parameters as variables of the formulas. The mission parameters are mapped by user inputs and user options (Figure 3).

The GUI is drawn in according to the project loaded at startup. The main window of the tool is logically divided in four areas:

1. Title bar: contains the version of the application and the name of the loaded project (the red bordered area of the Figure 4).
2. Banner area: describes the working area. Contains the title and a brief description of the actual page (the green bordered area of the Figure 4).
3. Working area: contains the data of the project, that the user can change, and the results of the system (the blue bordered area of the Figure 4).
4. Buttons area: contains the controls of the application (the orange bordered area of the Figure 4).

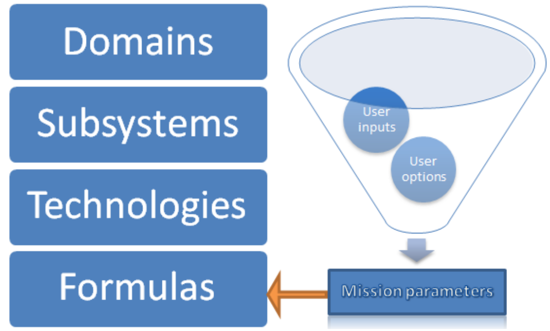

Figure 3. Logical structure

When the user opens a project, the application shows the “User inputs” area (Figure 4). The user input group’s name is used to render the title of the corresponding section. Each variable, instead, will be drawn in a list with three columns:

1. The name of the variable.
2. The unit of the variable.
3. The editor of the variable.

The editor used by the GUI depends on the type of the variable. For text variables, the GUI uses a simple text-field or, if the file defines, for the variable, a list of possible values, then the GUI draws a combo-box-field. For numerical variables, the GUI uses a spinner-text-field that permit to insert the number or to use the arrow buttons to increase or decrease the variable value. If the file defines the warning and error thresholds then the editor can’t exceed the error thresholds. Meanwhile, the tool shows a warning icon (on the name of the variable and on the Next button) when the user selects a value that exceeds the warning threshold. If the variable is a boolean then the GUI draws a mutual-exclusive couple of buttons: Yes/No.

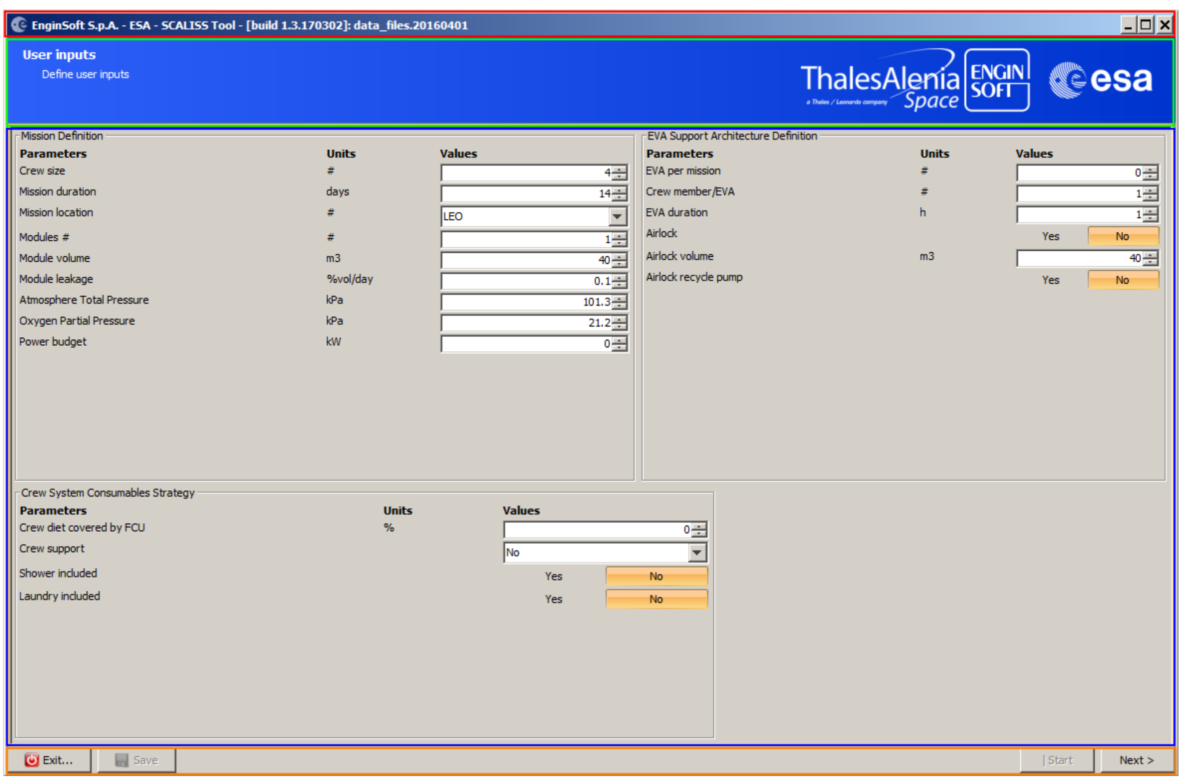

Figure 4. SCALISS GUI Main Window – User Inputs.

When the user press the “Next >” buttons inside the “User inputs” area then the application goes on the “User options” area (Figure 5). The user option group’s name is used to render the title of the corresponding section. Each variable, instead, will be drawn in a list with two columns:

1. The name of the variable.
2. The Yes/No mutual-exclusive couple of buttons.

If the variable has set the read-only flag then the pressed button can’t be changed.

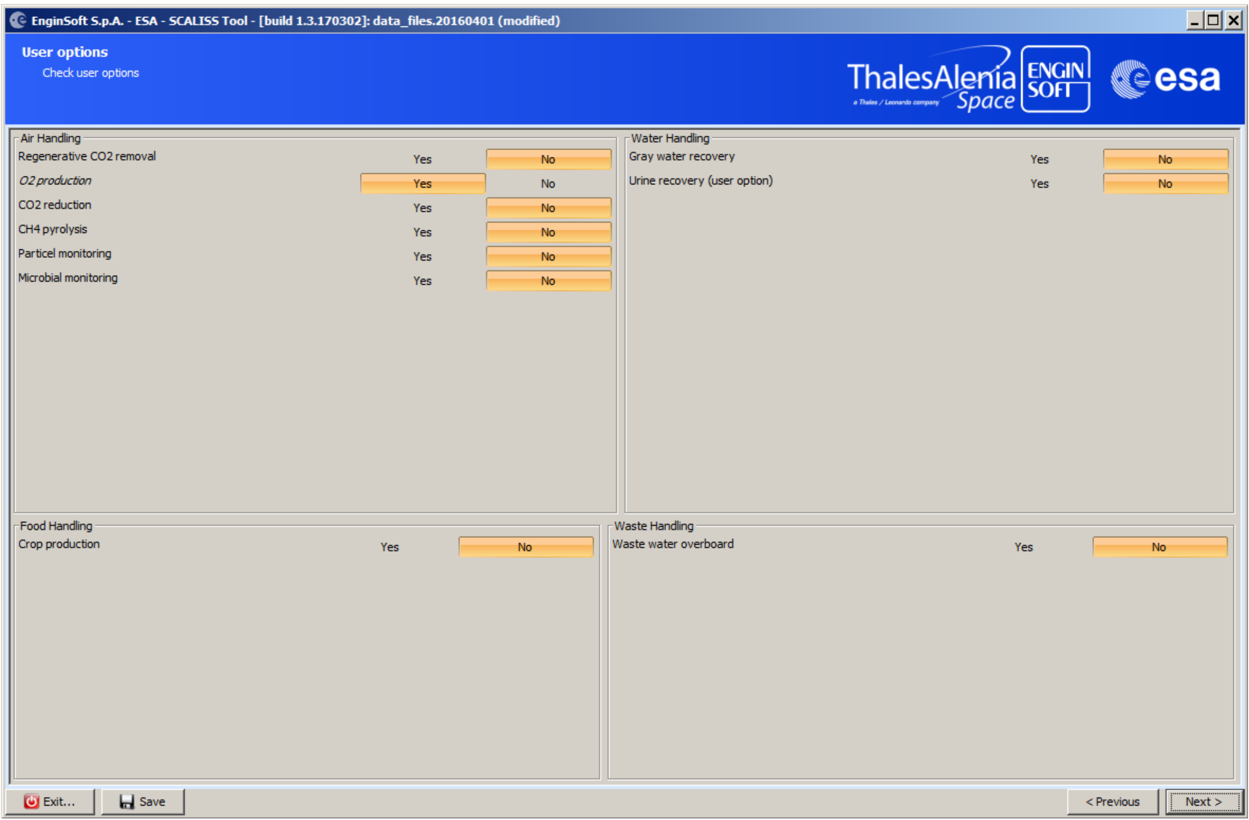

Figure 5. GUI User Options.

The “Domains” area (Figure **6**) is drawn by the application always in the same way. The bottom section of the area contains the domains tabs. There is a tab for each domain of the system. The tab is identified by the Unique-ID of the domain. The working area contains a section for each subsystem of the domain. Every subsystem has a title on the upper left corner of its panel and a description in the top of the panel. The possible technologies used by the subsystem are listed with a checkbox. The user can hit the checkbox to indicate if the technology is used or not inside the subsystem.

In the SCALISS model a technology can be implemented by different formulas for different criteria of calculation. For example, the technology “ACLS Oxygen regeneration system” can be implemented only by a formula for each criteria with limited data from paper ICES-2016-417. In the future another entity, or the Technology owner itself could develop a better toolbox/model for this technology and SCALISS would allow selection of the preferred one. The user can choose the implementation for every criteria using a combo-box that list all possible formulas available for the technology.

Right to the technology name there is a button used to open the “justification” file. Each technology can be linked to a “justification” file. The file can use the internal format or every format the operating system can handle.

The last area of the application is the results one (Figure 7). This area mimics the “Domains” one. For each technology there is the a result for each criteria, calculated using the selected formulas. At the bottom of each list of technologies, there are the total sums of the calculation of the selected technologies (only the flagged technologies). At the bottom of the area, there are the total sums of all the subsystems of the domain. The “Results” area has the “Summary” tab that summarizes the sum of all the domain calculations.

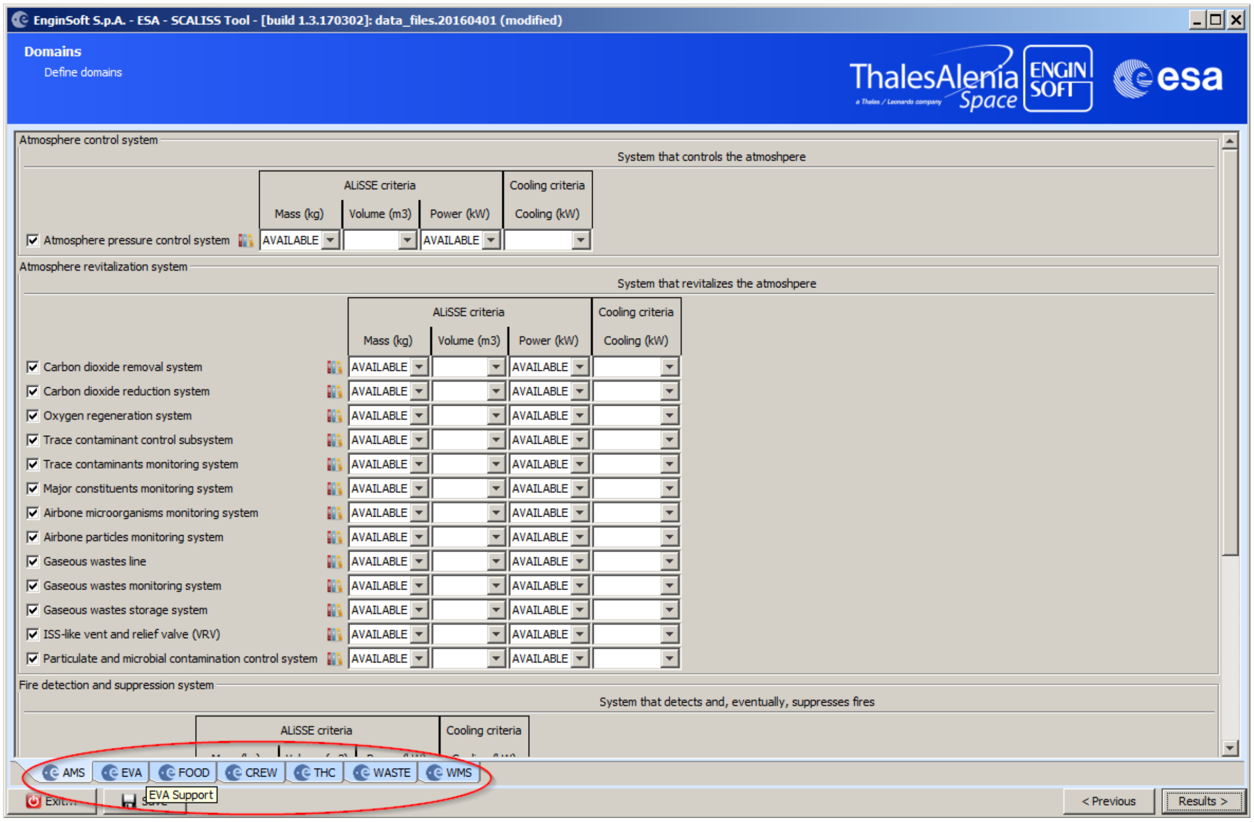

Figure 6. GUI Domains.

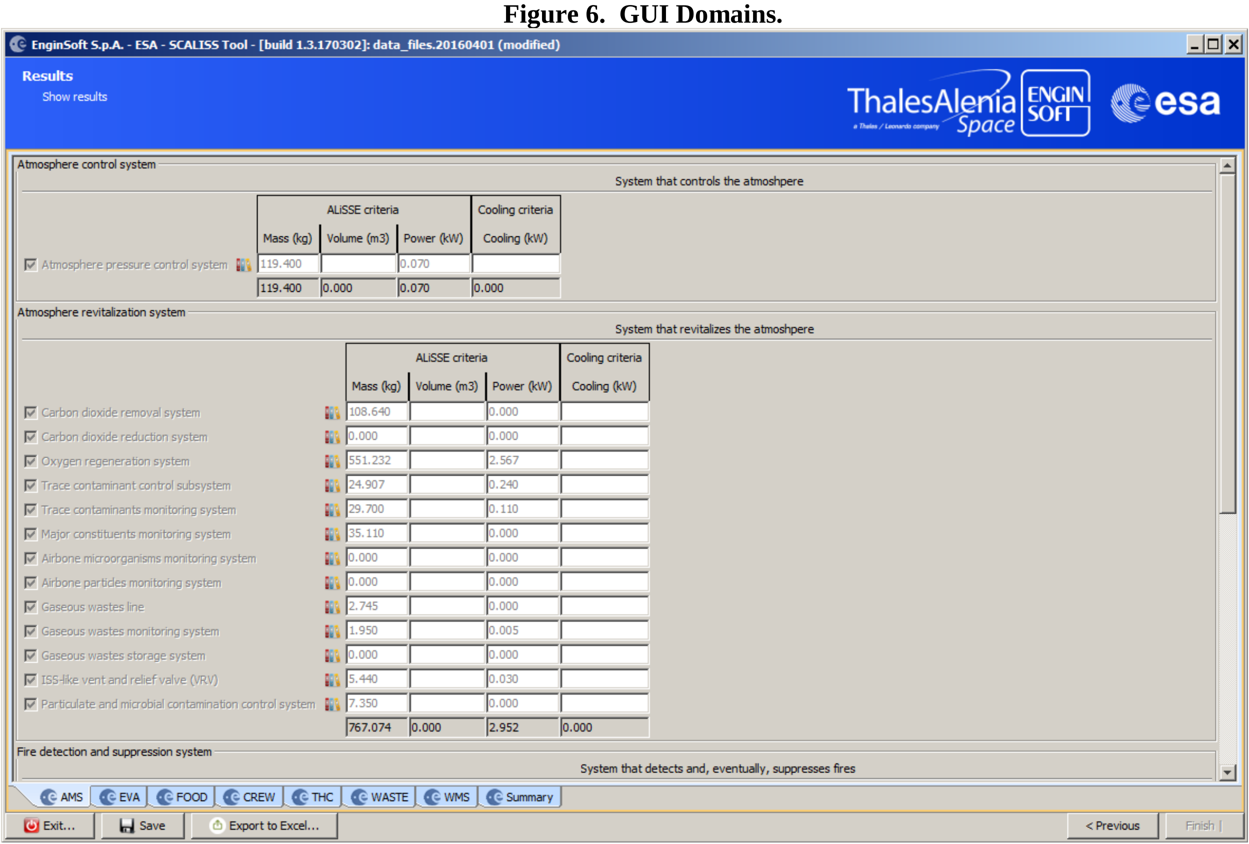

Figure 7. GUI Results Area.

The “Export to Excel…” button appears only if the application is showing the “Results” area. This button is used to export the data and results of the model to an external Microsoft Excel document. The typical output of this operation is visible in the Appendix.

IV. Case study results and SCALISS limits analysis

SCALISS was applied for ECLSS sizing of the six identified scenarios. The results are reported fully in Appendix (Table 5 to Table 7). An analysis of the result was performed within the study, mostly relying on available ECLSS sizing results from published literature on NASA ALSSAT case studies[3], highlighting necessary improvements that could be targeted in a future SCALISS upgrade activity. These improvements are summarized as follows:

- The TCCS is sized considering most of the mass dependent of crew size and mission duration, considering mainly the activated carbon mass; however this is negligible with respect to the other components mass for short term missions. The related assumptions need to be reviewed.
- The conditions for inclusion or not of an Oxygen recharge compressor assembly in support to EVA operations need to be reviewed.
- The gasses mass balance seems conservative for oxygen need, while not conservative enough for nitrogen need if compared to NASA ALSSAT performance: further investigation is needed.
- The sizing models used for SCALISS could be further revised with more details to be provided by technology owners.
- It is necessary to further upgrade SCALISS in order to allow the user choosing among multiple technologies for the same function, thus including ALS technologies (e.g. for water recovery).
- The Food Complement Unit model relies on data from the ESA FCU study, which was representative of a small rack-like facility targeting much lower growth surfaces, thus not at all optimized for the considered contribution. It is necessary to develop new models for large bio-regenerative elements (including also other MELiSSA compartments), in order to further improve SCALISS toward long term exploration scenarios.

In addition to the above identified possible improvements, the following intended upgrades are identified. The way the project uses to generate the graphical interface of new projects can be modified so to have the following additional functions:

- Possibility to define the layout of the first two “windows” that compose the SCALISS wizard
- Possibility to create new domains from the GUI
- Possibility to create new subsystems from the GUI
- Possibility to create new technologies and formulas from the GUI
- Possibility to create new models linking user inputs and mission parameters from the GUI

Moreover, it is possible to modify the application in order to allow management of multiple projects simultaneously. In addition to simplify the use of the instrument (improving accessibility and speed of use), this would allow comparison of multiple models (which are considered compatible).

Last, it is possible to create an ALiSSE node which would allow execution of a SCALISS model within the execution flux of ALiSSE. This would allow mapping the results of a SCALISS model compatible with the ALiSSE criteria with the results of the same ALiSSE criteria. This functionality could be provided with two approaches:

- Creation of an ALiSSE model that utilizes a batch node that recalls opportunely the modified SCALISS node
- Modification of ALiSSE in order to foresee the possibility of inserting a SCALISS node created for this

V. Conclusions

This paper described the SCALISS tool now available to ESA. The tool implements an ECLSS automated scaling methodology to perform phase A studies of manned missions. It is currently validated to address human missions (e.g. planetary/low orbit base, transit mission, etc.) to all destinations of interest including LEO, CIS-Lunar space and interplanetary space (e.g. Mars, asteroid, etc.), and for missions with duration of up to 600 days and a crew of up to 6 astronauts. Currently the tool allows preliminary calculation of components mass and power consumption. Future improvements of the tool have been identified and described.

Appendix

Table 4: List of technologies covered by SCALISS (build 1.1.160418)

ID	Function	Component	Technology	Technology Owner
T001	Control atmosphere total pressure	Atmosphere Pressure Control System	ISS APCS	NASA
T002	Monitor oxygen partial pressure	Major Constituents Monitoring System	ISS Air Sample Delivery System + ISS MCA	NASA
T003	Remove Carbon dioxide from atmosphere	Carbon Dioxide Removal System	ISS 4BMS (if regenerative) ISS LiOH (if not regenerative)	NASA
T004	Carbon dioxide reduction	Carbon Dioxide Reduction System	ACLS Sabatier Reactor	ESA/'Airbus DS
T005	Remove gaseous atmospheric contaminants	Trace Contaminant Control Subsystem	ISS TCCS	NASA
T006	Monitor trace gases in atmosphere	Trace Contaminants Monitoring System	ANITAII	Kayser-Threde GmbH
T007	Monitor airborne particles in atmosphere	Airborne particles monitoring system	P-Trak®	TSI
T008	Remove airborne microbes	Particulate and microbial contamination control system	ISS Columbus-like HEPA filter	ESA
T009	Monitor airborne microorganisms in atmosphere	Airborne microorganisms monitoring system	MIDASS	ESA/BioMérieux
T010	Regenerate oxygen	Oxygen regeneration system	ACLS OGA	ESA/'Airbus DS
T011	Transport gaseous wastes	Gaseous Wastes Line	ISS Gaseous Wastes Line	NASA
T012	Monitor gaseous wastes	Gaseous Wastes Monitoring System	ISS Gaseous Wastes Monitoring System	NASA
T013	Store gaseous wastes	Gaseous Wastes Storage System	ISS high pressure storage	NASA
T014	Dispose Excess Gaseous Wastes	Vent and Relief Valve (VRV)	ISS VRV	NASA
T015	Support contaminant detection and decontamination	Covered by T005 and T006	N/A	-
T016	Detect fire	Fire detection system	ISS Smoke Detector	NASA
T017	Suppress fire	Fire suppression system	ISS Portable Fire Exstinguisher	NASA
T018	Supply inert gas	Inert gas supply system	ISS Inert gas supply system	NASA
T019	Store inert gas	Inert gas storage system	ISS high pressure storage	NASA
T020	Supply oxygen	Oxygen supply system	ISS Oxygen supply system	NASA
T021	Store oxygen	Oxygen storage system	ISS high pressure storage	NASA
T022	Support extravehicular mobility unit servicing and checkout	Oxygen Recharge Compressor Assembly for EVA	ISS ORCA	NASA
T023	Support desorption of inert gas from body tissues	EVA Umbilical Assembly	ISS EVA Umbilical Assembly	NASA
T024	Support despressurization for egress	Airlock Recycle Pump	ISS Airlock Recycle Pump	NASA
T025	Support repressurization for ingress	Covered by T001	N/A	-
T026	Support EVA radiation monitoring	EVA Radiation Monitoring System	ISS EVA Radiation Monitoring badges	NASA
T027	Support EVA waste collection	EVA Maximum Abosorbency Garments	ISS MAGs	NASA
T028	Support EVA CO2 removal	EVA CO2 Removal System	LiOH	NASA
T029	Store food and food ingedients	Food storage system	ISS Ambient food storage system	NASA
T030	Produce food	Food Complement Unit	ESA FCU Study technology	ESA/TASI
T031	Monitor produced food quality	Produced food quality monitoring system	Portable PCR	NASA
T032	Regenerate food and food ingredients	Food and food ingredients regeneration system	ISS Sink & spigot (rehydration system)	NASA
T033	Process food and food ingredients	Food and food ingredients processing system	None selected	-

ID	Function	Component	Technology	Technology Owner
T034	Monitor Radiation	Radiation monitoring system	BP Bubble Detector (radiation monitoring)	BTI
T035	Provide human protection	Portable Breathing Apparatus (PBA)	ISS PBA	NASA
T036	Provide Clothing	Clothing	Non-reusable clothing (w/o Laundry) Washable clothing (with Laundry)	NASA
T037	Provide Laundry equipment	Laundry Equipment	ALS Washing machine + Clothes dryer	NASA
T038	Provide Personal Hygiene Services	Wet wipes	ISS shower wet wipes	NASA
T039	Provide Shower equipment	Shower	ALS Shower	NASA
T040	Maintain temperature	Cabin Air THC Assembly	ISS Common Cabin Air Assembly (CCAA)	NASA
T041	Accept thermal energy	Avionic Air THC Assembly	ISS Avionic Air Assembly (AAA)	NASA
T042	Transport thermal energy assembly	Internal Thermal Control System	ISS ITCS technology	NASA
T043	Control ventilation velocities in the crew habitable volume	Cabin Ventilation Assembly	ISS Node 1 Cabin Fan Assembly	NASA
T044	Exchange atmosphere between modules	Intermodule Ventilation Assembly	ISS IMV Assembly	NASA
T045	Accept solid and concentrated liquid wastes	Commode/ Urinal	ISS Commode/ Urinal	NASA
T046	Store solid and concentrated liquid wastes	Solid Wastes Storage System	ISS Solid Wastes Storage System	NASA
T047	Process solid and concentrated liquid wastes	Solid and concentrated liquid wastes processing system	ISS Trash Compactor	NASA
T048	Supply water	Water supply system	ISS Water supply system	NASA
T049	Store water	Potable Water storage system	MPCV for long missions, otherwise ATV	ESA/TASI
T050	Regenerate water	Water regeneration system	Water regeneration system (ISS WPA or ISS WPA+UPA)	NASA
T051	Transport wastewater	Wastewater collection/transportationsystem	ISS Wastewater collection/transportation system	NASA
T052	Monitor wastewater	Wastewater monitoring system	ISS Process Control (PCWQM)	NASA
T053	Store wastewater	Wastewater storage system	ISS CWC and ISS EDV	NASA
T054	Process wastewater	Wastewater processing system	ALS Urine pre-treatment assembly	NASA
T055	Dispose of excess wastewater	Overboard Water Vent Assembly	ISS Overboard Water Vent Assembly	NASA

Table 5: ECLSS Sizing of SEV (left) and MTOM (right)

Space Exploration Vehicle (SEV) ECLSS	ALiSSE criteria Mass (kg)	Power (kW)
Air Management System	357.85	0.456
Atmosphere control system	119.40	0.070
Atmosphere pressure control system	119.40	0.070
Atmosphere revitalization system	161.27	0.385
Carbon dioxide removal system (incl. consumables)	54.32	0.000
Carbon dioxide reduction system (incl. consumables)	0.00	0.000
Oxygen regeneration system (incl. consumables)	0.00	0.000
Trace contaminant control subsystem (incl. consumables)	24.69	0.240
Trace contaminants monitoring system	29.70	0.110
Major constituents monitoring system	35.11	0.000
Airborne microorganisms monitoring system	0.00	0.000
Airborne particles monitoring system	0.00	0.000
Gaseous wastes line	2.71	0.000
Gaseous wastes monitoring system	1.95	0.005
Gaseous wastes storage system	0.00	0.000
ISS-like vent and relief valve (VRV)	5.44	0.030
Particulate and microbial contamination control system	7.35	0.000
Fire detection and suppression system	9.29	0.001
Fire detection system	1.54	0.001
Fire suppression system	7.75	0.000
Gas storage	67.89	0.000
Inert gas storage system	6.55	0.000
Inert gas supply system	4.66	0.000
Nitrogen (gas)	11.78	0.000
Oxygen storage system	11.15	0.000
Oxygen supply system	4.58	0.000
Oxygen (gas)	29.17	0.000
EVA Support	216.12	1.640
EVA support system	216.12	1.640
EVA CO2 removal system (incl. consumables)	9.15	0.000
EVA maximum absorbency garments	1.38	0.000
EVA radiation monitoring system	0.10	0.000
EVA umbilical assembly	43.00	0.140
Oxygen recharge compressor assembly for EVA	162.48	1.500
Airlock recycle pump	0.00	0.000
Food Management	35.90	0.000
Food processing and storage system	35.90	0.000
Food and food ingredients regeneration system	15.00	0.000
Food storage system	3.63	0.000
Food (partially hydrated)	17.28	0.000
Food production system	0.00	0.000
Food complement unit (incl. consumables)	0.00	0.000
Produced food quality monitoring system	0.00	0.000
Crew accommodation system	23.18	0.000
Crew emergency provisions	3.13	0.000
Portable breathing apparatus (PBA)	3.00	0.000
Radiation monitoring system	0.13	0.000
Crew support system	20.05	0.000
Clothing	13.61	0.000
Laundry equipment	0.00	0.000
Shower	0.00	0.000
Wet wipes	6.44	0.000
Thermal Management System	186.51	0.005
Temperature and humidity control system	156.97	0.000
Cabin air THC assembly	119.62	0.000
Avionic air THC assembly	12.40	0.000
Cabin ventilation assembly	24.95	0.000
Intermodule ventilation assembly	0.00	0.000
Internal thermal control system	29.54	0.005
Internal thermal control system	29.54	0.005
Waste Management	78.75	0.000
Solid waste processing system	78.75	0.000
ISS commode/urinal	45.00	0.000
Solid and concentrated liquid wastes processing system	27.00	0.000
Solid waste storage system	6.75	0.000
Water Management	473.05	0.092
Water storage	376.18	0.016
Potable water storage system	23.79	0.000
Potable water	222.60	0.000
Waste water storage system	108.59	0.000
Water supply system	19.74	0.016
Overboard water vent assembly	1.46	0.000
Water recovery system	96.87	0.076
Water recovery system (incl. consumables)	0.00	0.000
Waste water collection/transportation system	19.74	0.016
Waste water monitoring system	38.00	0.050
Waste water stabilization system	39.13	0.010
Totals	1371.35	2.193

Man Tended Orbital Module (MTOM) ECLSS	ALiSSE criteria Mass (kg)	Power (kW)
Air Management System	651.17	0.458
Atmosphere control system	119.40	0.070
Atmosphere pressure control system	119.40	0.070
Atmosphere revitalization system	324.93	0.387
Carbon dioxide removal system (incl. consumables)	217.28	0.000
Carbon dioxide reduction system (incl. consumables)	0.00	0.000
Oxygen regeneration system (incl. consumables)	0.00	0.000
Trace contaminant control subsystem (incl. consumables)	25.34	0.242
Trace contaminants monitoring system	29.70	0.110
Major constituents monitoring system	35.11	0.000
Airborne microorganisms monitoring system	0.00	0.000
Airborne particles monitoring system	0.00	0.000
Gaseous wastes line	2.76	0.000
Gaseous wastes monitoring system	1.95	0.005
Gaseous wastes storage system	0.00	0.000
ISS-like vent and relief valve (VRV)	5.44	0.030
Particulate and microbial contamination control system	7.35	0.000
Fire detection and suppression system	9.29	0.001
Fire detection system	1.54	0.001
Fire suppression system	7.75	0.000
Gas storage	197.55	0.000
Inert gas storage system	14.66	0.000
Inert gas supply system	4.71	0.000
Nitrogen (gas)	26.37	0.000
Oxygen storage system	40.70	0.000
Oxygen supply system	4.63	0.000
Oxygen (gas)	106.48	0.000
EVA Support	281.25	2.640
EVA support system	281.25	2.640
EVA CO2 removal system (incl. consumables)	4.58	0.000
EVA maximum absorbency garments	0.69	0.000
EVA radiation monitoring system	0.20	0.000
EVA umbilical assembly	43.00	0.140
Oxygen recharge compressor assembly for EVA	162.48	1.500
Airlock recycle pump	70.30	1.000
Food Management	98.62	0.000
Food processing and storage system	98.62	0.000
Food and food ingredients regeneration system	15.00	0.000
Food storage system	14.51	0.000
Food (partially hydrated)	69.10	0.000
Food production system	0.00	0.000
Food complement unit (incl. consumables)	0.00	0.000
Produced food quality monitoring system	0.00	0.000
Crew accommodation system	86.45	0.000
Crew emergency provisions	6.26	0.000
Portable breathing apparatus (PBA)	6.00	0.000
Radiation monitoring system	0.26	0.000
Crew support system	80.19	0.000
Clothing	54.43	0.000
Laundry equipment	0.00	0.000
Shower	0.00	0.000
Wet wipes	25.76	0.000
Thermal Management System	186.51	0.005
Temperature and humidity control system	156.97	0.000
Cabin air THC assembly	119.62	0.000
Avionic air THC assembly	12.40	0.000
Cabin ventilation assembly	24.95	0.000
Intermodule ventilation assembly	0.00	0.000
Internal thermal control system	29.54	0.005
Internal thermal control system	29.54	0.005
Waste Management	98.99	0.000
Solid waste processing system	98.99	0.000
ISS commode/urinal	45.00	0.000
Solid and concentrated liquid wastes processing system	27.00	0.000
Solid waste storage system	26.99	0.000
Water Management	1187.03	0.253
Water storage	518.00	0.016
Potable water storage system	8.98	0.000
Potable water	84.00	0.000
Waste water storage system	403.82	0.000
Water supply system	19.74	0.016
Overboard water vent assembly	1.46	0.000
Water recovery system	669.03	0.237
Water recovery system (incl. consumables)	572.16	0.161
Waste water collection/transportation system	19.74	0.016
Waste water monitoring system	38.00	0.050
Waste water stabilization system	39.13	0.010
Totals	2590.01	3.356

Table 6: ECLSS Sizing of LDSS (left) and MTV (right)

Lunar Destination Surface System (LDSS) ECLSS	ALiSSE criteria Mass (kg)	Power (kW)
Air Management System	1861.22	6.119
Atmosphere control system	119.40	0.070
Atmosphere pressure control system	119.40	0.070
Atmosphere revitalization system	1421.44	6.048
Carbon dioxide removal system (incl. consumables)	137.50	0.395
Carbon dioxide reduction system (incl. consumables)	335.17	0.258
Oxygen regeneration system (incl. consumables)	782.07	4.885
Trace contaminant control subsystem (incl. consumables)	27.53	0.249
Trace contaminants monitoring system	29.70	0.110
Major constituents monitoring system	35.11	0.000
Airborne microorganisms monitoring system	55.00	0.110
Airborne particles monitoring system	1.87	0.006
Gaseous wastes line	2.74	0.000
Gaseous wastes monitoring system	1.95	0.005
Gaseous wastes storage system	0.00	0.000
ISS-like vent and relief valve (VRV)	5.44	0.030
Particulate and microbial contamination control system	7.35	0.000
Fire detection and suppression system	9.29	0.001
Fire detection system	1.54	0.001
Fire suppression system	7.75	0.000
Gas storage	311.09	0.000
Inert gas storage system	18.80	0.000
Inert gas supply system	4.69	0.000
Nitrogen (gas)	33.81	0.000
Oxygen storage system	68.90	0.000
Oxygen supply system	4.61	0.000
Oxygen (gas)	180.27	0.000
EVA Support	423.48	2.640
EVA support system	423.48	2.640
EVA CO2 removal system (incl. consumables)	128.13	0.000
EVA maximum absorbency garments	19.38	0.000
EVA radiation monitoring system	0.20	0.000
EVA umbilical assembly	43.00	0.140
Oxygen recharge compressor assembly for EVA	162.48	1.500
Airlock recycle pump	70.30	1.000
Food Management	307.66	0.000
Food processing and storage system	307.66	0.000
Food and food ingredients regeneration system	15.00	0.000
Food storage system	50.79	0.000
Food (partially hydrated)	241.86	0.000
Food production system	0.00	0.000
Food complement unit (incl. consumables)	0.00	0.000
Produced food quality monitoring system	0.00	0.000
Crew accommodation system	316.18	2.600
Crew emergency provisions	6.26	0.000
Portable breathing apparatus (PBA)	6.00	0.000
Radiation monitoring system	0.26	0.000
Crew support system	309.92	2.600
Clothing	11.76	0.000
Laundry equipment	208.00	2.600
Shower	0.00	0.000
Wet wipes	90.16	0.000
Thermal Management System	186.51	0.005
Temperature and humidity control system	156.97	0.000
Cabin air THC assembly	119.62	0.000
Avionic air THC assembly	12.40	0.000
Cabin ventilation assembly	24.95	0.000
Intermodule ventilation assembly	0.00	0.000
Internal thermal control system	29.54	0.005
Internal thermal control system	29.54	0.005
Waste Management	166.47	0.000
Solid waste processing system	166.47	0.000
ISS commode/urinal	45.00	0.000
Solid and concentrated liquid wastes processing system	27.00	0.000
Solid waste storage system	94.47	0.000
Water Management	2060.23	0.730
Water storage	377.44	0.016
Potable water storage system	50.09	0.000
Potable water	159.00	0.000
Waste water storage system	147.15	0.000
Water supply system	19.74	0.016
Overboard water vent assembly	1.46	0.000
Water recovery system	1682.79	0.714
Water recovery system (incl. consumables)	1585.93	0.638
Waste water collection/transportation system	19.74	0.016
Waste water monitoring system	38.00	0.050
Waste water stabilization system	39.13	0.010
Totals	5321.74	12.094

Mars Transit Vehicle (MTV) ECLSS	ALiSSE criteria Mass (kg)	Power (kW)
Air Management System	3627.87	8.821
Atmosphere control system	119.40	0.070
Atmosphere pressure control system	119.40	0.070
Atmosphere revitalization system	2054.16	8.750
Carbon dioxide removal system (incl. consumables)	185.39	0.557
Carbon dioxide reduction system (incl. consumables)	523.51	0.394
Oxygen regeneration system (incl. consumables)	1221.53	7.362
Trace contaminant control subsystem (incl. consumables)	41.32	0.292
Trace contaminants monitoring system	29.70	0.110
Major constituents monitoring system	35.11	0.000
Airborne microorganisms monitoring system	0.00	0.000
Airborne particles monitoring system	0.00	0.000
Gaseous wastes line	2.86	0.000
Gaseous wastes monitoring system	1.95	0.005
Gaseous wastes storage system	0.00	0.000
ISS-like vent and relief valve (VRV)	5.44	0.030
Particulate and microbial contamination control system	7.35	0.000
Fire detection and suppression system	9.29	0.001
Fire detection system	1.54	0.001
Fire suppression system	7.75	0.000
Gas storage	1445.01	0.000
Inert gas storage system	46.86	0.000
Inert gas supply system	4.82	0.000
Nitrogen (gas)	84.28	0.000
Oxygen storage system	360.67	0.000
Oxygen supply system	4.73	0.000
Oxygen (gas)	943.66	0.000
EVA Support	0.00	0.000
EVA support system	0.00	0.000
EVA CO2 removal system (incl. consumables)	0.00	0.000
EVA maximum absorbency garments	0.00	0.000
EVA radiation monitoring system	0.00	0.000
EVA umbilical assembly	0.00	0.000
Oxygen recharge compressor assembly for EVA	0.00	0.000
Airlock recycle pump	0.00	0.000
Food Management	1627.59	0.000
Food processing and storage system	1627.59	0.000
Food and food ingredients regeneration system	15.00	0.000
Food storage system	279.87	0.000
Food (partially hydrated)	1332.72	0.000
Food production system	0.00	0.000
Food complement unit (incl. consumables)	0.00	0.000
Produced food quality monitoring system	0.00	0.000
Crew accommodation system	429.36	2.600
Crew emergency provisions	9.38	0.000
Portable breathing apparatus (PBA)	9.00	0.000
Radiation monitoring system	0.38	0.000
Crew support system	419.98	2.600
Clothing	64.80	0.000
Laundry equipment	208.00	2.600
Shower	97.50	0.000
Wet wipes	49.68	0.000
Thermal Management System	186.51	0.005
Temperature and humidity control system	156.97	0.000
Cabin air THC assembly	119.62	0.000
Avionic air THC assembly	12.40	0.000
Cabin ventilation assembly	24.95	0.000
Intermodule ventilation assembly	0.00	0.000
Internal thermal control system	29.54	0.005
Internal thermal control system	29.54	0.005
Waste Management	592.56	0.000
Solid waste processing system	592.56	0.000
ISS commode/urinal	45.00	0.000
Solid and concentrated liquid wastes processing system	27.00	0.000
Solid waste storage system	520.56	0.000
Water Management	5170.77	1.169
Water storage	1151.67	0.016
Potable water storage system	75.13	0.000
Potable water	238.50	0.000
Waste water storage system	816.84	0.000
Water supply system	19.74	0.016
Overboard water vent assembly	1.46	0.000
Water recovery system	4019.10	1.153
Water recovery system (incl. consumables)	3922.24	1.077
Waste water collection/transportation system	19.74	0.016
Waste water monitoring system	38.00	0.050
Waste water stabilization system	39.13	0.010
Totals	11634.66	12.595

Table 7: ECLSS Sizing of MDAL (left) and MSHL (right)

Mars Ascent Descent Lander (MDAL) ECLSS	ALiSSE criteria	
	Mass (kg)	Power (kW)
Air Management System	839.44	0.46
Atmosphere control system	119.40	0.07
Atmosphere pressure control system	119.40	0.07
Atmosphere revitalization system	457.34	0.39
Carbon dioxide removal system (incl. consumables)	349.20	0.00
Carbon dioxide reduction system (incl. consumables)	0.00	0.00
Oxygen regeneration system (incl. consumables)	0.00	0.00
Trace contaminant control subsystem (incl. consumables)	25.87	0.24
Trace contaminants monitoring system	29.70	0.11
Major constituents monitoring system	35.11	0.00
Airborne microorganisms monitoring system	0.00	0.00
Airborne particles monitoring system	0.00	0.00
Gaseous wastes line	2.72	0.00
Gaseous wastes monitoring system	1.95	0.01
Gaseous wastes storage system	0.00	0.00
ISS-like vent and relief valve (VRV)	5.44	0.03
Particulate and microbial contamination control system	7.35	0.00
Fire detection and suppression system	9.29	0.00
Fire detection system	1.54	0.00
Fire suppression system	7.75	0.00
Gas storage	253.41	0.00
Inert gas storage system	9.03	0.00
Inert gas supply system	4.67	0.00
Nitrogen (gas)	16.23	0.00
Oxygen storage system	60.53	0.00
Oxygen supply system	4.59	0.00
Oxygen (gas)	158.36	0.00
EVA Support	280.55	2.64
EVA support system	280.55	2.64
EVA CO2 removal system (incl. consumables)	3.43	0.00
EVA maximum absorbency garments	1.04	0.00
EVA radiation monitoring system	0.30	0.00
EVA umbilical assembly	43.00	0.14
Oxygen recharge compressor assembly for EVA	162.48	1.50
Airlock recycle pump	70.30	1.00
Food Management	149.38	0.00
Food processing and storage system	149.38	0.00
Food and food ingredients regeneration system	15.00	0.00
Food storage system	23.32	0.00
Food (partially hydrated)	111.06	0.00
Food production system	0.00	0.00
Food complement unit (incl. consumables)	0.00	0.00
Produced food quality monitoring system	0.00	0.00
Crew accommodation system	138.26	0.00
Crew emergency provisions	9.38	0.00
Portable breathing apparatus (PBA)	9.00	0.00
Radiation monitoring system	0.38	0.00
Crew support system	128.88	0.00
Clothing	87.48	0.00
Laundry equipment	0.00	0.00
Shower	0.00	0.00
Wet wipes	41.40	0.00
Thermal Management System	186.51	0.01
Temperature and humidity control system	156.97	0.00
Cabin air THC assembly	119.62	0.00
Avionic air THC assembly	12.40	0.00
Cabin ventilation assembly	24.95	0.00
Intermodule ventilation assembly	0.00	0.00
Internal thermal control system	29.54	0.01
Internal thermal control system	29.54	0.01
Waste Management	115.38	0.00
Solid waste processing system	115.38	0.00
ISS commode/urinal	45.00	0.00
Solid and concentrated liquid wastes processing system	27.00	0.00
Solid waste storage system	43.38	0.00
Water Management	2400.08	0.09
Water storage	2303.22	0.02
Potable water storage system	152.94	0.00
Potable water	1431.00	0.00
Waste water storage system	698.08	0.00
Water supply system	19.74	0.02
Overboard water vent assembly	1.46	0.00
Water recovery system	96.87	0.08
Water recovery system (incl. consumables)	0.00	0.00
Waste water collection/transportation system	19.74	0.02
Waste water monitoring system	38.00	0.05
Waste water stabilization system	39.13	0.01
Totals	4109.60	3.20

Mars Surface Habitat Lander (MSHL) ECLSS	ALiSSE criteria	
	Mass (kg)	Power (kW)
Air Management System	4811.59	9.008
Atmosphere control system	119.40	0.070
Atmosphere pressure control system	119.40	0.070
Atmosphere revitalization system	2185.63	8.937
Carbon dioxide removal system (incl. consumables)	185.39	0.557
Carbon dioxide reduction system (incl. consumables)	542.52	0.399
Oxygen regeneration system (incl. consumables)	1265.88	7.393
Trace contaminant control subsystem (incl. consumables)	52.55	0.327
Trace contaminants monitoring system	29.70	0.110
Major constituents monitoring system	35.11	0.000
Airborne microorganisms monitoring system	55.00	0.110
Airborne particles monitoring system	1.87	0.006
Gaseous wastes line	2.86	0.000
Gaseous wastes monitoring system	1.95	0.005
Gaseous wastes storage system	0.00	0.000
ISS-like vent and relief valve (VRV)	5.44	0.030
Particulate and microbial contamination control system	7.35	0.000
Fire detection and suppression system	9.29	0.001
Fire detection system	1.54	0.001
Fire suppression system	7.75	0.000
Gas storage	2497.27	0.000
Inert gas storage system	101.73	0.000
Inert gas supply system	4.82	0.000
Nitrogen (gas)	182.96	0.000
Oxygen storage system	609.18	0.000
Oxygen supply system	4.73	0.000
Oxygen (gas)	1593.86	0.000
EVA Support	797.58	2.640
EVA support system	797.58	2.640
EVA CO2 removal system (incl. consumables)	400.40	0.000
EVA maximum absorbency garments	121.10	0.000
EVA radiation monitoring system	0.30	0.000
EVA umbilical assembly	43.00	0.140
Oxygen recharge compressor assembly for EVA	162.48	1.500
Airlock recycle pump	70.30	1.000
Food Management	25175.28	35.922
Food processing and storage system	2702.65	0.000
Food and food ingredients regeneration system	15.00	0.000
Food storage system	466.45	0.000
Food (partially hydrated)	2221.20	0.000
Food production system	22472.62	35.922
Food complement unit (incl. consumables)	22466.40	35.802
Produced food quality monitoring system	6.23	0.120
Crew accommodation system	505.68	2.600
Crew emergency provisions	9.38	0.000
Portable breathing apparatus (PBA)	9.00	0.000
Radiation monitoring system	0.38	0.000
Crew support system	496.30	2.600
Clothing	108.00	0.000
Laundry equipment	208.00	2.600
Shower	97.50	0.000
Wet wipes	82.80	0.000
Thermal Management System	186.51	0.005
Temperature and humidity control system	156.97	0.000
Cabin air THC assembly	119.62	0.000
Avionic air THC assembly	12.40	0.000
Cabin ventilation assembly	24.95	0.000
Intermodule ventilation assembly	0.00	0.000
Internal thermal control system	29.54	0.005
Internal thermal control system	29.54	0.005
Waste Management	939.60	0.000
Solid waste processing system	939.60	0.000
ISS commode/urinal	45.00	0.000
Solid and concentrated liquid wastes processing system	27.00	0.000
Solid waste storage system	867.60	0.000
Water Management	7228.71	1.169
Water storage	1696.23	0.016
Potable water storage system	75.13	0.000
Potable water	238.50	0.000
Waste water storage system	1361.40	0.000
Water supply system	19.74	0.016
Overboard water vent assembly	1.46	0.000
Water recovery system	5532.48	1.153
Water recovery system (incl. consumables)	5435.62	1.077
Waste water collection/transportation system	19.74	0.016
Waste water monitoring system	38.00	0.050
Waste water stabilization system	39.13	0.010
Totals	39644.94	51.344

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