PeaPod - Design Brief

Outlining the Requirements for a Submission to the

NASA/CSA Deep Space Food Challenge - Phase 1

Jayden Lefebvre - Lead Engineer

jayden.lefebvre@mail.utoronto.ca

Revision 0.4

University of Toronto Agritech

May 18th, 2021

Contents

1 Introduction

1.1 Purpose

The purpose of this design brief is to outline the requirements for a submission to the NASA/CSA Deep Space Food Challenge Phase 1 [1]. In doing so, it also documents the scope of a design submitted by University of Toronto Agritech (UTAG).

The goal of the Deep Space Food Challenge is for participants to "Create novel food production technologies or systems that require minimal inputs and maximize safe, nutritious, and palatable food outputs for long-duration space missions, and which have potential to benefit people on Earth." [2]

1.2 Framing Structure

This document achieves its purpose via "top-down" framing (Section 2), with each subsection's entries being derived from the entries of the previous[1].

- **2.1 - Opportunity**: A succinct scoped challenge statement.
- **2.2 - Challenge Requirements**: Categorical/unscoped requirements for *any* submission.
- **2.3 - Stakeholders**: Persons and groups in consideration.
- **2.4.1 - High-Level Objectives**: Conceptual aims, DfX; derived from Requirements and Stakeholders.
- **2.4.2 - Low-Level Objectives**: Tactical goals; derived from HLOs.
- **2.5 - Metrics**: Quantitative measures of design success, fit, utility, etc.; derived from LLOs.
- **2.6 - Constraints**: Scoped *mandatory* requirements for the proposed design.
- **2.7 - Criteria**: Scoped *optional* requirements for the proposed design.

In addition to framing the challenge, this document serves to outline the structural requirements of the Phase 1 prototypes (See Appendices A, B).

[1] Each objective and metric has a numbered reference to the entry it was derived from (**S**takeholder **1** : S1, **H**igh-**L**evel Objective **8** : HL8, etc.)

1.3 Scope and Justification

Phase 1 development, testing, and assessment is scoped to terrestrial/Earth-like operational constraints [2]:

- Gravity (9.81 m/s^2);
- Ambient atmospheric pressure (101,325 Pa);
- Ambient atmospheric/"room" temperature (22 °C);
- Ambient atmospheric humidity (50 %RH);

In addition, it is important to note that the solution "need not meet the full nutritional requirements of future crews, but can contribute significantly to, and integrate with, a comprehensive food system." [2] However, in implementation it can be assumed that this would be the only crop growth system on-board, and as such would need to provide the majority.

The three underlined criteria in the challenge statement in Section 1.1 have also helped to define the scope of this brief:

1. The longer the duration of the space mission (up to and including interplanetary travel and permanent colonization) the lesser the feasability of resupply [2].
2. The lesser the feasability of resupply, and the more minimal the input (i.e. launch mass), the more the design will need to generate net-new food grown on-board during the mission [3].
3. The minimization of inputs (launch mass), the minimization of other negative criteria such as growth time, design complexity, etc. and the maximization of safety (pathogenic and otherwise) means that food animal growth has been deemed not feasible, and is outside the scope of this brief. Thus, the design should focus on food-producing plant (or crop) growth[4].
4. Spacecraft are not good crop growth systems (lack of water access, proper lighting and nutrition, etc.), thus the design should encompass a crop growth environment that:

[2] Minimal resupply is also listed as a constraint directly in the challenge details [2].

[3] Any other food production technologies would be taking advantage of existing food; as such this is the basis for the problem.

[4] This is primarily an issue in-transit; for colonization, non-plant food production systems should definitely be considered.

(a) provides of all necessary crop growth inputs (water, nutrients, lighting, etc.);

(b) contains or otherwise encompasses a viable crop growth environment (temperature, humidity, gas concentrations, airflow, etc.);

(c) has control over all parameters of both a) and b) (environment parameters); these together are the (crop growth) environment conditions.

5. To maximise safety (of both the crops and the crew) and redundancy, and to minimize inputs (required human interaction), the environment should be automated and isolated from the spacecraft cabin with regards to all environment conditions (thermally, water-tight, etc.) unless beneficial and efficient (i.e no loss).

6. A greater degree of nutrition and palatability of food outputs implies a greater variety of crops (incl. leafy greens, fruits/fruiting vegetables, root vegetables, algaes, etc.); as such the food production system should be able to generate a continuous variety of environmental conditions such that any number of food crops could be grown within.

7. The demand for high crop variety, automation, parameter control, etc. implies the use of a hydroponic/aeroponic/hybrid crop growth method.

8. Output nutrient and yield maximization in a controlled-environment implies environment parameter optimization. This is best accomplished via collection of both plant-growth and environment metrics and cross-growth-environment networking (data versatility, sharing, and machine intelligence).

1.4 Definitions

A number of useful definitions have emerged from the above scoping:

1. **(Crop Growth) Environment** - The environment within which the crop grows/with which the crop interacts; the Environment Parameters in terms of their relationship with the crop and its growth.
2. **(Crop Growth) Environment Parameters** - The (often quantitative) parameters of the Crop Growth Environment, as well as any and all other parameters influencing crop growth.
3. **Crop Growth System** - Includes the physical enclosure (containing the crops and the controlled environment; incl. isolation) as well as any infrastructure required to generate the crop growth environment and control all environment conditions; satisfies all requirements of this brief.
4. **Crop Growth Metrics** - The (often quantitative) measures of crop growth optimization, including yield mass, growth rate, nutrient/etc. concentrations, etc.
5. **Environment Program** - The to-date most optimized set of Environment Parameters for a given Crop Growth Metric, implemented by the Grop Growth System.

2 Framing

2.1 Opportunity

Design a fully automated and isolated hydroponic/aeroponic crop growth system for the Deep Space Food Challenge Phase 1[1], able to generate any environment from a combination of independent environment parameters, with crop-growth and environment data collection.

2.2 Challenge Requirements

The following are the overall challenge requirements compiled from DSFC Applicant Guide details [2] and an excerpt of NASA-STD-3001: Section 7.1 Food and Nutrition[5] [3]:

R1. **Must** help fill food gaps for a *three-year* round-trip mission with *no resupply*:

   (a) **Should** aim to produce food outputs that fulfill **all daily nutritional needs** for a crew of *four (4)* people;

   (b) **Must** maintain food output *safety* and *nutrition* during *all phases* of the mission;

   (c) **Must** output food that is *acceptable* to the crew for the *duration* of the mission;

   (d) **Must** produce *varied palatable* food outputs that require *no additional processing time*[6];

R2. **Should** improve the accessibility of food on Earth; in particular, via production directly in urban centres and in remote and harsh environments:

   (a) **Should** enhance local production;

   (b) **Should** reduce food supply chain shortages;

   (c) **Should** reduce the impact on the resources needed for food production;

   (d) **Should** be able to operate in harsh and remote environments;

R3. **Must** aim to achieve the *greatest of food output* with *minimal inputs* and *minimal waste*;

R4. **Must** transmit *operational data and limited video* to a remote location, and be able to receive periodic *operational commands.*

R5. **Must** operate under Earth-like conditions (See Section 1.3);

[5] Additional nutrition and caloric output constraints relative to activity level, crew details, etc. are provided; however they are not in direct consideration as of Phase 1.

[6] It is assumed that fresh (or packaged unprepared) edible plant products are already prepared on existing space missions, and that this preparation meets this requirement.

2.3 Stakeholders

S1. Food Product Consumers - Palatability, output

S2. NASA/CSA Stakeholders - Feasability, input, optimization

2.4 Objectives

2.4.1 High-Level

HL1. Food Output Suitability (S1, R1, R1a, R2a)

HL2. Environment Control, Automation, and Optimization (S2, R1b, R2c, R2d, R3, R4)

HL3. Efficiency (S1, S2, R1, R2a, R2c, R3)

HL4. Cross-Contamination (S1, S2, R1c)

HL5. Feasability (S2, R2c)

2.4.2 Low-Level

LL1. Output Food Variety (HL1)

LL2. Output Food Palatability (HL1)

LL3. Nutrient Output (HL1, HL3)

LL4. Energy Output (HL1, HL3)

LL5. Air Temperature Control (HL2)

LL6. Air Humidity Control (HL2)

LL7. Lighting Control (HL2)

LL8. Light Isolation (HL2, HL3)

LL9. Thermal Isolation (HL2, HL3)

LL10. Water-tightness (HL2, HL4)

LL11. Airflow (HL2, HL4)

LL12. Water Flow Rate (HL2)

LL13. Water Temperature (HL2)

LL14. Germination Success (HL2)

LL15. High Degree of Automation (HL3, HL4)

LL16. Energy Efficiency (HL3)

LL17. Water Usage Efficiency (HL3)

LL18. Time-To-Harvest/-Reharvest (HL3)

LL19. Germination Time (HL3)

LL20. Growth Time (HL3)

LL21. Potential for Cross-Contamination (HL4)

LL22. Cost (HL5)

LL23. Size (HL5)

2.5 Metrics

#	Metric		Units
M1	Variety of Suitable Crops	(LL1)	Y/N (per crop)
M2	Palatability of Crop Output vs. Commercial	(LL2)	1-10 Hedonic (per crop)
M3	Crop Nutrient Concentration vs. Commercial	(LL3)	% (per crop)
M4	Crew Nutrient Requirement Coverage	(LL3)	% (best crop combo)
M5	Caloric Output per Day	(LL4)	kCal/24hr (best crop combo)
M6	Air Temperature Control Range	(LL5)	min, max °C
M7	Air Temperature Control Rate	(LL5)	Δ°C/sec at each °C
M8	Air Temperature Control Stability	(LL5)	±°C at each °C
M9	Air Humidity Control Range	(LL6)	min, max %RH
M10	Air Humidity Control Rate	(LL6)	Δ%RH/sec at each %RH
M11	Air Humidity Control Stability	(LL6)	±%RH at each %RH
M12	Light Spectrum Wavelength Range	(LL7)	min, max nm
M13	Light Spectrum PAR Match	(LL7)	% (each crop)
M14	Light Intensity Control Range	(LL7)	min, max μmol $m^{-2}sec^{-1}$ at each nm
M15	Light Intensity Control Stability	(LL7)	$\pm\mu$mol $m^{-2}sec^{-1}$ at each nm
M16	Light Loss, Capture by Surfaces	(LL8)	%
M17	Outside Light Penetration	(LL8)	%
M18	Heat Loss	(LL9)	±W at each °C
M19	Water Loss due to Leaks, Evaporation	(LL10)	mL/hr
M20	Internal Circulation Airflow Control Range	(LL11)	min, max m^3/min
M21	Gas Exchange due to Leaks	(LL11)	m^3/min
M22	Maximum Intentional Gas Exchange	(LL11)	m^3/min
M23	Nutrient Solution Delivery Control Range	(LL12)	min, max mL/sec
M24	Nutrient Solution Delivery Control Rate	(LL12)	ΔmL/sec^2 at each mL/sec
M25	Nutrient Solution Delivery Control Stability	(LL12)	±mL/sec at each mL/sec
M26	Nutrient Solution Temp. Control Range	(LL13)	min, max °C
M27	Nutrient Solution Temp. Control Rate	(LL13)	°C/sec at each °C
M28	Nutrient Solution Temp. Control Stability	(LL13)	±°C at each °C
M29	Germination Success Rate	(LL14)	%
M30	Time Requirement - Maintenance	(LL15)	hrs/week
M31	Time Requirement - Setup	(LL15)	hrs
M32	Energy Efficiency - Power vs. kCal	(LL16)	%
M33	Necessary Water Waste per Day	(LL17)	L/day
M34	Initial Water Requirement	(LL17)	L
M35	Harvest to Reharvest - Fruiting Crops	(LL18)	min (each crop)
M36	Germination Time	(LL19)	min (each crop)
M37	Seedling to Harvest	(LL20)	min (each crop)
M38	Potential for Contamination - Germination	(LL21)	% (each event)
M39	Potential for Contamination - Planting	(LL21)	% (each event)

2.5 Metrics (Cont'd)

#	Metric		Units
M40	Potential for Contamination - Harvest	(LL21)	% (each event)
M41	Cost	(LL22)	CAD
M42	Outer Dimensions	(LL23)	m (W, D, H)
M43	Outer Volume	(LL23)	m^3
M44	Power Consumption	(LL23)	W
M45	Mass	(LL23)	kg

2.6 Constraints

Metric	Constraint	Source
M30	4 hrs/week	[2]
M42	Fits through 1.07m x 1.90m doorway; W<1.829m, D<2.438m, H<2.591m	[2]
M43	$\leq 2\ m^3$	[2]
M44	Avg. <1500W; Peak < 3000W	[2]

2.7 Criteria

Metric	Criteria; Reason	Source
M19	Minimize; Reduce System Inputs	[2]
M33	Minimize; Reduce System Inputs	[2]
M34	Maximize; Reduce System Inputs	[2]
M45	Minimize; Reduce System Inputs	[2]

Refer to Appendix A for prototype verification Assessment Criteria (categories, weights, etc.).

Appendices

A Assessment Criteria

A.1 Report Assessment Criteria

Category	Description	Maximum Points	Percent of Score
Overall Criteria			
Adherence to Constraints	Does the food technology design adhere to the constraints described in Table 1?	Y/N	0%
Design Approach and Innovation	Does the design approach the problem of food production technology for spaceflight in a novel and innovative way?	15	15%
Scientific and Technical Merit	Does the scientific and technical approach and design of the technology demonstrate merit?	15	15%
Feasibility of Design	Is the proposed technical approach feasible? To what extent does the Team clearly understand and address any potential risks in their design submission?	15	15%
Terrestrial Potential	To what extent does the Design Report present a feasible scenario for the potential use of the technology within terrestrial food systems?	15	15%
Subtotal		60	60%
Performance Criteria			
Acceptability	Acceptability of the food production process; and Acceptability of the resulting food products	10	10%
Safety	NOTE: Designs that fail to account for pathogens will receive a "fail" score in the Safety category. Safety of the food production process, including environmental safety; and Safety of the resulting food products, including safety for human consumption.	10	10%
Resource Inputs / Outputs	Resource requirements of the food production process (inputs) and all outputs; the amount of food output in relation to the inputs and waste; and nutritional quality of the resulting food products	10	10%
Reliability/Stability	Stability of the inputs and outputs; reliability of the technology with less than 10% loss of functionality or food production	10	10%
Subtotal		40	40%
Total		100	100%

Figure 1: Design report assessment categories and weights [2].

A.2 Animation Assessment Criteria

Category	Description	Maximum Points	Percent of Score
Accuracy	Does the Design Animation present an accurate visual representation of the food production technology described in the Design Report and its operation?	10	67%
Engages the Public	Is the Design Animation engaging for a public audience?	5	33%
Total		15	100%

Figure 2: Design animation assessment categories and weights [2].

B Application Details

The contents of this appendix are adapted from [2], and should serve as the framework for developing the Phase 1 prototype.

A complete application package consists of the Challenge Application Form, with the following sections:

1. Applicant details (basic information, primary contact);
2. Proposed solution details:
   (a) Design Abstract;
   (b) Design Report (See Appendix A.1);
   (c) Design Animation (video; See Appendix A.2);
   (d) Intellectual Property Details;
3. Declaration (terms and conditions, Consent for Use, Disclosure and Copyright requirements);
4. Survey (optional);

References

[1] “Deep Space Food Challenge,” Impact Canada, launched by NASA/CSA. [Online]. Available: https://impact.canada.ca/en/challenges/deep-space-food-challenge

[2] “DSFC Applicant Guide,” Impact Canada, launched by NASA/CSA. [Online]. Available: https://impact.canada.ca/en/challenges/deep-space-food-challenge/application-guide

[3] “Excerpt of NASA-STD-3001: Section 7.1 Food and Nutrition,” National Aeronautics and Space Administration, Standard, 02 2015. [Online]. Available: https://impact.canada.ca/challenges/deep-space-food-challenge/excerpt