

PeaPod - Design Brief

Submission to the NASA/CSA Deep Space Food Challenge - Phase 1

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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 previous¹.

- **2.1 - Opportunity:** A succinct scoped challenge statement.
- **2.2 - Requirements:** Categorical or scoping constraints.
- **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.

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

¹Each objective and metric has a numbered reference to the entry it was derived from (Stakeholder 1 : S1, High-Level 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 feasibility of resupply ².
2. The lesser the feasibility 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) growth⁴.
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:

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

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

⁴This 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, algae, 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.

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 environment, as well as any and all other parameters relevant to 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.

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.

2.2 Requirements

Compiled from DSFC Applicant Guide details [2] and an excerpt of NASA-STD-3001: Section 7.1 Food and Nutrition⁵ [3]:

1. *Helps* fill food gaps for a **three-year** round-trip mission with **no resupply**:
 - (a) Feeds a crew of **four (4)** people;
 - (b) Provides the capability to maintain food safety and nutrition **during all phases** of the mission;
 - (c) Provides food that is *acceptable* to the crew **for the duration** of the mission;
 - (d) Produces **varied, safe, nutritious, and palatable** food outputs that can provide **all daily nutritional needs** and require **little processing time**⁶ for crew members;
2. Improve the accessibility of food on Earth; in particular, via production directly in urban centres and in remote and harsh environments:
 - (a) Enhance local production;
 - (b) Reduce food supply chain shortages;
 - (c) Reduce the impact on the resources needed for food production;
 - (d) Able to operate in harsh and remote environments;

⁵Additional 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.

⁶It is assumed that fresh (or packaged unprepared) edible plant products are already prepared on existing space missions, and that this preparation meets this requirement; thus, preparation time is outside the scope of this design brief.

3. Achieve the **greatest amount of food output** with **minimal inputs** and **minimal waste**;
4. Transmits **operational data and limited video** to a remote location, and receives periodic **operational commands**.

Extracted from scoping:

4. Must be able to operate under Earth-like conditions (See Section 1.3);

2.3 Stakeholders

1. Food Product Consumers
2. NASA/CSA Stakeholders - Spacecraft feasibility and optimization criteria
3. Crops - Crop growth metrics

2.4 Objectives

2.4.1 High-Level

- | | |
|--|--|
| 1. Food Output Suitability (S1, R1, R1a, R2a) | 4. Cross-Contamination (S1, S2, R1c) |
| 2. Environment Control, Automation, and Optimization (S2, S3, R1b, R2c, R2d, R3) | 5. Safety, Redundancy (S1, S2, R1b, R2b) |
| 3. Efficiency (S1, S2, R1, R2a, R2c, R3) | 6. Modularity, Repairability (S1, S2, R2d) |
| | 7. Feasibility (S2) |

2.4.2 Low-Level

- | | |
|-------------------------------------|---|
| 1. Output Food Variety (HL1) | 20. Gas Exchange Incentive (HL3) |
| 2. Output Food Palatability (HL1) | 21. Number of Harvests (HL3) |
| 3. Nutrient Output (HL1) | 22. Time-To-Harvest/-Reharvest (HL3) |
| 4. Energy Output (HL1, HL4) | 23. Germination Time (HL3) |
| 5. Air Temperature Control (HL2) | 24. Growth Time (HL3) |
| 6. Air Humidity Control (HL2) | 25. Potential for Cross-Contamination (HL4) |
| 7. Gas Concentration Control (HL2) | 26. Structural Safety (HL5) |
| 8. Lighting Control (HL2) | 27. Electrical/Power Safety (HL5) |
| 9. Light Isolation (HL2) | 28. Power Supply Redundancy (HL5) |
| 10. Thermal Isolation (HL2) | 29. Infrastructure Redundancy (HL5) |
| 11. Water-tightness (HL2, HL5) | 30. Growth Container Modularity (HL6) |
| 12. Airflow (HL2) | 31. Infrastructure Modularity Support (HL6) |
| 13. Water Flow Rate (HL2) | 32. Growth Container Repairability (HL6) |
| 14. Water Temperature (HL2) | 33. Infrastructure Repairability (HL6) |
| 15. Germination Success (HL2) | 34. Documentation Completion (HL6) |
| 16. High Degree of Automation (HL3) | 35. Design Complexity (HL6) |
| 17. Energy Efficiency (HL3) | 36. Tool Speciality and Number (HL6) |
| 18. Water Usage Efficiency (HL3) | 37. Cost (HL7) |
| 19. Plant Matter Usage (HL3) | 38. Size (HL7) |

2.5 Metrics

#	Metric		Units
1	Number of Suitable Crop Species	(LL1)	# (per crop)
2	Quality/Palatability of Crop Output	(LL2)	1-10 (per crop)
3	Crop Nutrient Concentration	(LL3)	% (per crop)
4	Protein Output Density	(LL3)	g/kg
5	Protein Output	(LL3)	kCal/crewmember (%TDEI)
6	Carbohydrate Output	(LL3)	kCal/crewmember (%TDEI)
7	Lipid Output	(LL3)	kCal/crewmember (%TDEI)
8	Ω -6 Fatty Acid Output	(LL3)	g/day/crewmember
9	Ω -3 Fatty Acid Output	(LL3)	g/day/crewmember
10	Saturated Fat Output	(LL3)	kCal/crewmember (%TDEI)
11	Trans Fatty Acids Output	(LL3)	kCal/crewmember (%TDEI)
12	Cholesterol Output	(LL3)	mg/day/crewmember
13	Fiber Output	(LL3)	g/day/crewmember
14	Caloric Output per Day	(LL4)	kCal/24hr
15	Air Temperature Control Range	(LL5)	min, max °C
16	Air Temperature Control Rate	(LL5)	°C/sec at each °C
17	Air Temperature Control Stability	(LL5)	±°C at each °C
18	Air Humidity Control Range	(LL6)	min, max %RH
19	Air Humidity Control Rate	(LL6)	%RH/sec at each %RH
20	Air Humidity Control Stability	(LL6)	±%RH at each %RH
21	CO ₂ Concentration Control Range	(LL7)	min, max ppm CO ₂
22	CO ₂ Concentration Control Rate	(LL7)	ppm CO ₂ /sec at each ppm CO ₂
23	CO ₂ Concentration Control Stability	(LL7)	±ppm CO ₂ at each ppm CO ₂
24	O ₂ Concentration Control Range	(LL7)	min, max ppm O ₂
25	O ₂ Concentration Control Rate	(LL7)	ppm O ₂ /sec at each ppm O ₂
26	O ₂ Concentration Control Stability	(LL7)	±ppm O ₂ at each ppm O ₂
27	Light Spectrum Wavelength Control Range	(LL8)	min, max nm
28	Light Spectrum PAR Match	(LL8)	% (each crop)
29	Light Spectrum Intensity Control Range	(LL8)	min, max $\mu\text{mol m}^{-2}\text{sec}^{-1}$ at each nm
30	Light Spectrum Intensity Control Stability	(LL8)	± $\mu\text{mol m}^{-2}\text{sec}^{-1}$ at each nm
31	Light Captured by Non-Photosynthetic Surfaces	(LL9)	%
32	Outside Light Penetration	(LL9)	%
33	Heat Transfer	(LL10)	±W at each °C
34	Water Loss due to Leaks, Evaporation	(LL11)	mL/hr
35	Internal Circulation Airflow Control Range	(LL12)	min, max m ³ /min
36	Gas Exchange due to Leaks	(LL12)	m ³ /min
37	Maximum Intentional Gas Exchange	(LL12)	m ³ /min
38	Nutrient Solution Delivery Rate Control Range	(LL13)	min, max mL/plant/sec
39	Nutrient Solution Delivery Rate Control Rate	(LL13)	mL/plant/sec ² at each mL/plant/sec
40	Nutrient Solution Delivery Rate Control Stability	(LL13)	±mL/sec/plant at each mL/sec/plant

2.5 Metrics (Cont'd)

#	Metric	Units
41	Nutrient Solution Temperature Control Range (LL14)	min, max °C
42	Nutrient Solution Temperature Control Rate (LL14)	°C/sec at each °C
43	Nutrient Solution Temperature Control Stability (LL14)	±°C at each °C
44	Germination Success Rate (LL15)	%
45	Required Human Intervention Time - Maintenance (LL16)	hrs/week
46	Required Human Intervention Time - Setup (LL16)	hrs
47	Energy Efficiency - In (Power) vs. Out (kCal + Loss) (LL17)	%
48	Necessary Water Waste per Day (LL18)	L/day
49	Water Recycling from Spacecraft Systems (LL18)	L/day
50	Initial Water Requirement (LL18)	L
51	Plant Matter Usage (LL19)	%
52	CO ₂ Capture - Fraction of Typical Reclaimer Consumption (LL20)	%
53	O ₂ Production - Fraction of Typical Reclaimer Production (LL20)	%
54	Number of Harvests per Planting (LL21)	# (each crop)
55	Harvest to Reharvest - Fruiting Crops (LL22)	min (each crop)
56	Seedling to Harvest (LL22, LL24)	min (each crop)
57	Germination Time (LL23)	min (each crop)
58	Potential for Cross-Contamination - Germination (LL25)	% (each event)
59	Potential for Cross-Contamination - Planting (LL25)	% (each event)
60	Potential for Cross-Contamination - Harvest (LL25)	% (each event)
61	Factor of Safety (LL26)	FOS (each structure)
62	Mounting Stability - System to Surroundings (LL26)	FOS (each mount)
63	Mounting Stability - Infrastructure to System (LL26)	FOS (each mount)
64	Risk of Electrical Malfunction (LL27)	%
65	Backup Power Systems? (LL28)	Y/N
66	Incremental Power-On? (LL28)	Y/N
67	Backup Water Systems? (LL29)	Y/N
68	Infrastructure Failure Notification? (LL29)	Y/N
69	Independent Crop Growth Environments? (LL30)	Y/N
70	Support for N+1 Crop Growth Environments? (LL31)	Y/N
71	Lighting System Swappable? (LL32)	Y/N
72	Heating/Cooling System(s) Swappable? (LL32)	Y/N
73	Water Delivery System(s) Swappable? (LL32)	Y/N
74	Lighting System Swappable? (LL32)	Y/N
75	Computer Subsystems Swappable? (LL33)	Y/N
76	All Fabrication Procedures, Tools, and Materials Documented? (LL34)	Y/N
77	All Assembly Procedures, Tools, and Materials Documented? (LL34)	Y/N
78	All Repair Procedures, Tools, and Materials Documented? (LL34)	Y/N
79	Total Fabrication, Assembly, and Startup Time (LL35)	min
80	Total Number of Tools Required (LL36)	#

2.5 Metrics (Cont'd)

#	Metric	Units
81	Number of New Tools Required (LL36)	#
82	Cost (LL37)	CAD
83	Outer Dimensions (LL38)	m (W, D, H)
84	Outer Volume (LL38)	m ³
85	Power Consumption (LL38)	W
86	Mass (LL38)	kg

2.6 Constraints

Metric	Constraint	Source
M45	4 hrs/week	[2]
M83	Fits through 1.07m x 1.90m doorway; W<1.829m, D<2.438m, H<2.591m	[2]
M84	$\leq 2 \text{ m}^3$	[2]
M85	Avg. <1500W; Peak < 3000W	[2]

2.7 Criteria

Metric	Criteria; Reason	Source
M34	Minimize; Reduce System Inputs	[2]
M48	Minimize; Reduce System Inputs	[2]
M49	Maximize; Reduce System Inputs	[2]
M50	Minimize; Reduce System Inputs	[2]
M86	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>