Microgravity Blood Infusion Pump

PURDUE UNIVERSITY

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HuLC
HUMAN LANDER CHALLENGE

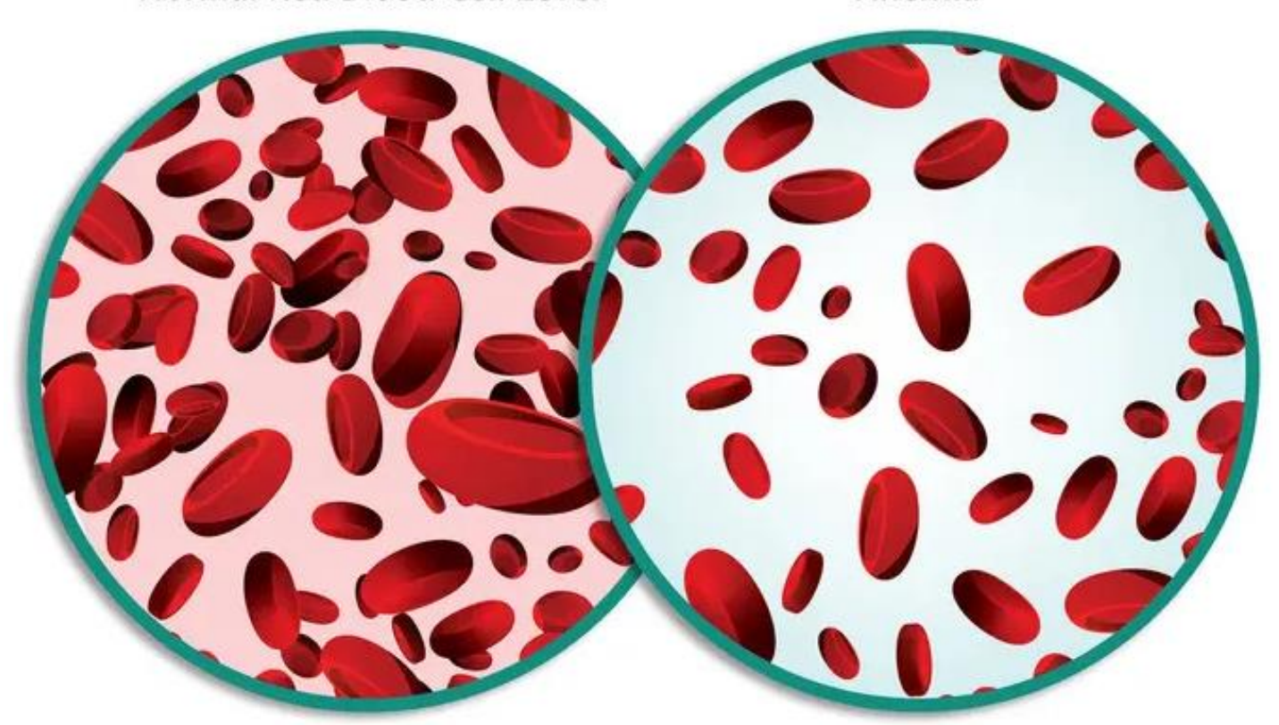
Background & Motivation

NASA's Artemis program extends human missions to 30 days on the Moon and up to 1,200 days for Mars transit, distances where medical evacuation is impossible. As more people live and work in space for long durations, the risk of severe hemorrhage or anemia becomes a critical concern. Blood transfusion can be a life-saving treatment, but no such solution currently exists for the microgravity environment. Conventional infusion systems rely on gravity-assisted flow and buoyancy-driven air separation, in microgravity, surface tension dominates fluid behavior, leaving gas bubbles suspended in the fluid path and creating serious air embolism risk. Even bubbles as small as 20 µL can be clinically dangerous.

Freeze-dried blood is the leading storage strategy for long-duration missions, and parabolic flight research has confirmed that rehydration in microgravity is feasible (Elder, 2024), but rehydration introduces air bubbles into the fluid line (Gao, 2025). Peristaltic pumps have also been demonstrated successfully moving IV fluid in microgravity (Spaulding, 2004), validating the core pumping mechanism. However, no integrated system exists that combines gravity-independent pumping with active bubble removal and detection.

The MBIP addresses that gap directly.

The Medical Need

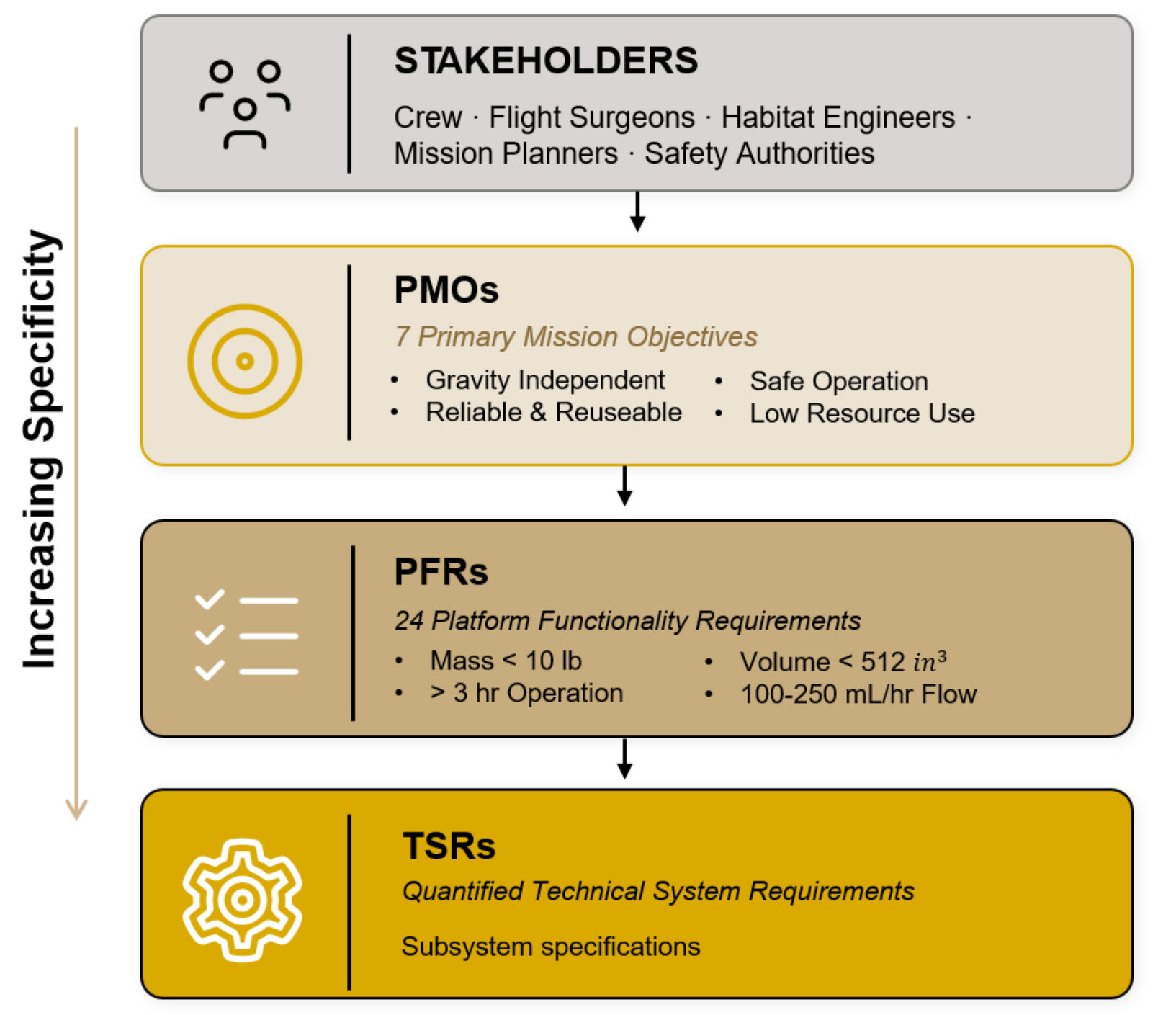


Mitchell, Kristin. "Iron Deficiency Anemia (Low Iron): Symptoms, Causes, Treatment." WebMD, WebMD, 26 Jan. 2026, www.webmd.com/a-to-z-guides/iron-deficiency-anemia.

Anemia — reduced red blood cell count impairs oxygen delivery, worsened by known space-induced physiological changes. Red blood cells die 54% faster (Sohn, 2022). Symptoms include fatigue, shortness of breath, dizziness, and impaired cognitive function, dangerous for a crew operating complex systems far from Earth.

Hemorrhage — traumatic blood loss can reach critical levels within minutes

Requirements & Systems Engineering



STAKEHOLDERS
Crew · Flight Surgeons · Habitat Engineers · Mission Planners · Safety Authorities

PMOs
7 Primary Mission Objectives
- Gravity Independent
- Reliable & Reuseable
- Safe Operation
- Low Resource Use

PFRs
24 Platform Functionality Requirements
- Mass < 10 lb
- > 3 hr Operation
- Volume < 512 in^3
- 100-250 mL/hr Flow

TSRs
Quantified Technical System Requirements
Subsystem specifications

KEY DESIGN DRIVERS

PMO-3 | Safety
Air $\geq 20\ \mu L$ shutoff
Hemolysis Index < 0.8%

PFR-11 | Mass
< 10 lb total system mass

PFR-12 | Volume
$\leq 512\ in^3$ stowed volume

PFR-24 | Flow Rate
100-250 mL/hr

System Design

Microgravity Blood Infusion Pump
Peristaltic pump + ePTFE bubble trap + sensor suite = safe blood infusion in 0g and low gravity environments

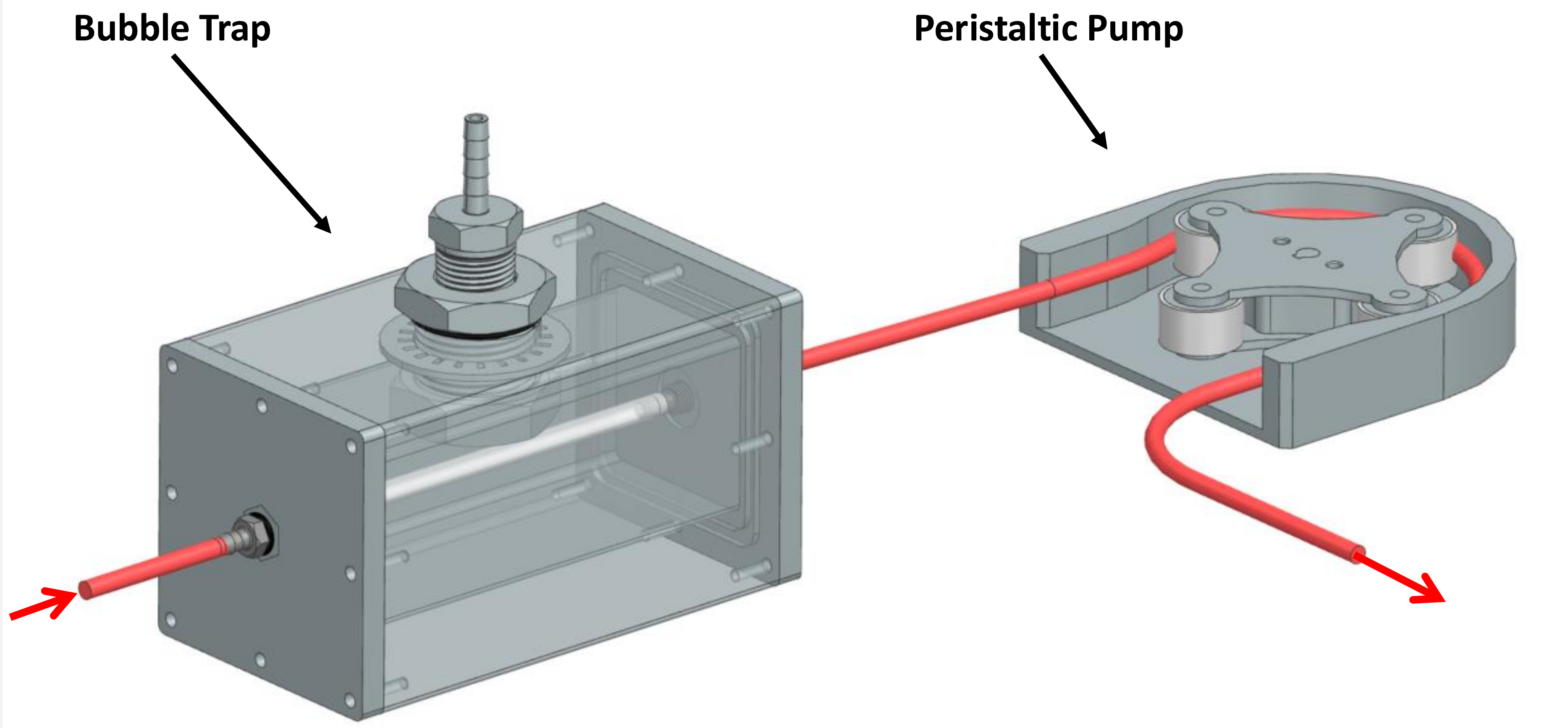
Gravity-independent flow — Peristaltic positive displacement replaces passive drip, operating across 0g, partial-g, and 1g environments.

Dual-layer bubble safety — ePTFE membrane passively removes bubbles; ultrasonic sensor triggers auto-shutoff for any remaining air ≥ 20 µL.

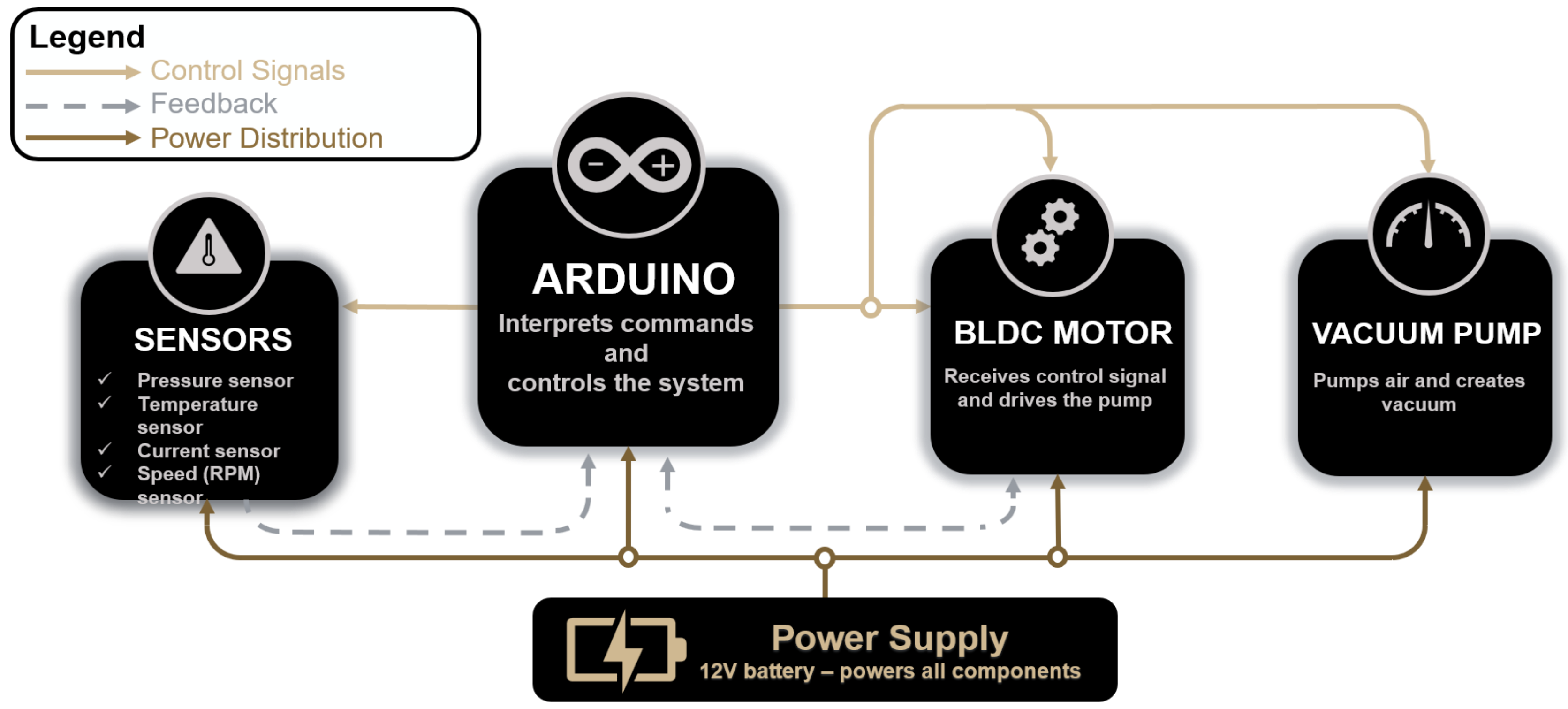
Closed-loop autonomy — Real-time flow, pressure, and battery monitoring within spacecraft mass, volume, and power constraints.

Specs: 400–500 mL/transfusion · 100–250 mL/hr flow rate · <3 W continuous · 4.56 lb total mass · 512 in³ stowed volume

Microgravity Blood Infusion Pump Assembly



Arduino Control System



SENSORS
- ✓ Pressure sensor
- ✓ Temperature sensor
- ✓ Current sensor
- ✓ Speed (RPM) sensor

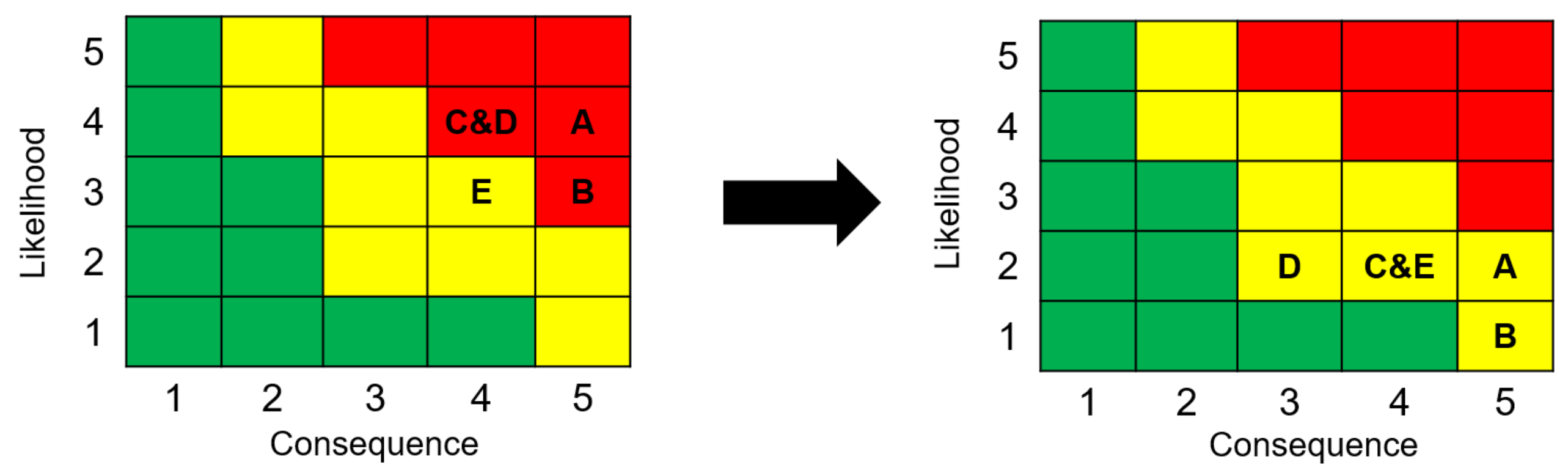
ARDUINO
Interprets commands and controls the system

BLDC MOTOR
Receives control signal and drives the pump

VACUUM PUMP
Pumps air and creates vacuum

Power Supply
12V battery – powers all components

Risk Analysis



ID	RISK	MITIGATION
A	Air Embolism	ePTFE trap + dual bubble sensors
B	Breach in Sterile Fluid Path	Closed, sterile disposable tubing set
C	Loss of Blood Delivery Capability	Motor torque margin + endurance validation testing
D	Vacuum Pump / Pressure Seal Failure	Pressure monitoring + leak testing protocol
E	Hemolysis	Peristaltic pump selection, compliant tubing + low speeds

Prototype Cost Breakdown

Component	Cost (USD)
BLDC Motor	$14
Vacuum Pump (KNF NMP 830)	$320
Arduino Microcontroller	$28
LiFePO₄ Battery (3Ah)	$32
Tubing & Connectors	$100
ePTFE Membrane Cartridge	$120
Metal Pump Housing	$100
Polycarbonate Housing	$100
Ultrasonic Bubble Detector	$250
Vacuum Pressure Sensor	$30
Load Cell	$15
Leak Detection Sensors	$20
MEMS Accelerometer	$20
Temperature Sensors	$20

Hardware Subtotal
$1,169

Testing & Contingency (~20%)
$234

Total Prototype Cost
$1,403

Future Steps

Lab Prototype *Years 0–1*	Integrate pump, bubble trap & control; validate flow accuracy & bubble detection; >3 hr endurance demo	**TRL 3 → 4**
Environmental Testing *Years 1-3*	Vibration & thermal cycling; parabolic flight validation of bubble removal & flow at 0g	**TRL 4 → 5**
Flight Engineering Model *Years 5-6*	Structural hardening, radiation-tolerant electronics; spacecraft power bus interface; integrated flight-like testing	**TRL 5 → 6**
Qualification & Integration *Years 5-8*	Qualification-level vibration & shock; hazard & safety certification; Artemis mission deployment readiness	**TRL 6 → 7/8**

★ Current Status: TRL 2–3 — Analytical modeling complete, motor control validated, prototype build in progress