NASA HUMAN HEALTH & PERFORMANCE GROUP

IV Fluid Administration in Microgravity

Student Project Brief

*Semester-Long Engineering Design Challenge | High School STEM- ** This brief is written as if you were working on this project every day for one semester. Most are working on this over the course of school year. Create a Ghant chart to help you schedule your tasks.***

1. Project Overview

You and your team have been given a real engineering challenge directly from NASA's Human Health and Performance (HH&P) group. Over this semester, your team of 3–5 students will design, build, and test a working prototype of an IV fluid administration system that can operate in microgravity — the weightless environment of space.

At the end of the semester, you will present your prototype and findings directly to the NASA HH&P team. This is not a simulation. The engineering problems you are solving are the same ones NASA engineers face when preparing for crewed missions to the Moon and Mars.

Your Mission

Design a compact, easy to set up, with disposable IV lines (including in-line filters) that is a crew operable IV fluid delivery system that works without gravity. Your system must:

- Deliver fluid at a controlled rate without relying on gravity to drive flow
- Eliminate air bubbles from the line before and during delivery
- Be set up and operated entirely by one crew member without ground support
- Meet basic safety standards for spaceflight medical equipment
- **Do NOT worry about bubbles in the IV bag. Only focus on the line from IV bag to the patient**

Why This Matters

Standard IV systems used in hospitals rely on gravity to drip fluid from a bag down into a patient's vein. In space, there is no gravitational pull, so this does not work. Bubbles that would naturally float to the top of an IV line on Earth do not rise in microgravity — they travel wherever the fluid goes, which can cause a potentially fatal air embolism.

Communication delays between Earth and deep-space missions can be up to 24 minutes each way, meaning astronauts cannot wait for ground support during a medical emergency. Your system must be simple enough for a non-medical crew member to set up and use without real-time help from Earth.

2. The Problem in Microgravity

Before you start designing, you need to understand exactly how microgravity changes the physics of IV fluid delivery. Four core problems must be addressed by your design:

Problem 1 — No Gravity-Fed Drip

On Earth, hanging an IV bag above the patient creates a hydrostatic pressure difference that drives fluid down the line and into the vein. In microgravity, there is no gravitational force to create this pressure difference. The fluid will simply float in the bag and will not flow unless actively pushed.

Problem 2 — Air Bubbles Don’t Rise

On Earth, air bubbles in an IV-line float upward and can be tapped out or caught by a drip chamber. (A drip chamber does not work)In microgravity, bubbles do not rise — they travel with the fluid flow wherever it goes. An air bubble that reaches a patient’s bloodstream can cause a gas embolism, which is life-threatening.

Problem 3 — No Buoyancy for Phase Separation

Standard in-line IV filters and air traps rely on the fact that gas is less dense than liquid and will naturally separate upward. In microgravity, density-driven separation does not occur. Your system needs a different mechanism to separate any entrained air from the fluid.

Problem 4 — Crew Autonomy Required

Astronauts on deep-space missions cannot call Earth for step-by-step instructions during an emergency. Your system must be intuitive enough for a crew member with basic training to prime and operate in under 90 seconds, without referring to complex manuals.

3. Functional Requirements

The following requirements define the minimum performance your prototype must achieve. These were developed by NASA's HH&P group based on human spaceflight medical standards (NASA-STD-3001, Vol. 2). You must address every required FR in your final prototype. Bonus FRs are optional stretch goals.

3.1 Fluid Delivery

ID	Requirement	Source
FR-3.1.1	The system shall deliver IV fluids at a controlled rate of 1–250 mL/hr, selectable by the crew member.	NASA-STD-3001
FR-3.1.2	The system shall maintain the set flow rate within ±10% throughout the duration of administration.	NASA-STD-3001
FR-3.1.3	The system shall accommodate standard 500 mL and 1000 mL IV fluid bags or pouches.	NASA-STD-3001
FR-3.1.4	The system shall be fully primed (air purged) in under 90 seconds from initiation.	HH&P Scope
FR-3.1.5	In-line filters shall be validated for the intended flow direction; push-versus-pull filter performance must be tested and documented.	HH&P Scope

3.2 Air Elimination

ID	Requirement	Source
FR-3.2.1	The system shall include an active mechanism to remove entrained air from the fluid line before fluid reaches the patient.	NASA-STD-3001
FR-3.2.2	The air elimination mechanism shall not rely on buoyancy or gravity-driven phase separation.	HH&P Scope
FR-3.2.3	The system shall prevent delivery of air boluses greater than 0.5 mL.	NASA-STD-3001
FR-3.2.4	The system shall include a visible indicator when the line has been successfully primed and is air-free.	HH&P Scope
FR-3.2.5	The administration line and air-elimination components shall be single-use and sterile; no portion of the fluid path shall be reused between patients.	HH&P Scope

3.3 Safety

ID	Requirement	Source
FR-3.3.1	All materials in the fluid path shall be biocompatible and meet the requirements of NASA-STD-3001 Vol. 2, Section 6.8.	NASA-STD-3001
FR-3.3.2	The system shall include an automatic or manual overpressure shutoff that activates if line pressure exceeds safe limits.	NASA-STD-3001

ID	Requirement	Source
FR-3.3.3	All connectors in the fluid path shall be fluid-sealed (Luer-lock or equivalent) to prevent fluid leakage during connect and disconnect operations.	HH&P Scope
FR-3.3.4	The system shall be operable by a single crew member with no real-time ground support. All required steps shall be completable using on-board crew training and on-device labeling.	HH&P Scope

3.4 Bonus Objectives (Optional Stretch Goals)

Teams that satisfy all required FRs may attempt the following bonus objectives for additional credit. These represent advanced capabilities that would improve the system for operational spaceflight use.

ID	Requirement	Source
FR-3.4.1 ★	BONUS: The system shall integrate an ultrasound-based bubble detector on the fluid line that provides a real-time alert when a bubble larger than 0.1 mL is detected.	HH&P Scope
FR-3.4.2 ★	BONUS: The system shall include a digital display or smartphone interface that shows current flow rate, volume delivered, and elapsed time.	HH&P Scope

4. Operational Requirements

In addition to the functional requirements above, your prototype must meet the following operational constraints. These reflect the realities of using medical equipment in a spacecraft.

ID	Requirement	Source
FR-4.1	The complete system (excluding fluid bag) shall have a mass of 2 kg or less and a stowed volume of 3 liters or less.	HH&P Scope
FR-4.2	The system shall operate on battery-operated power for a minimum of 4 hours continuous use. (If doing the bonus section)	HH&P Scope

5. Design Priorities

When design choices conflict, use this ranking to decide which constraint wins. Safety is always first. If your team is choosing between two approaches, always choose the one that better satisfies higher-ranked priorities.

Rank	Priority	Rationale
#1	**Patient Safety – Zero Air Embolism Risk**	Air in the bloodstream is fatal. Air elimination must work reliably with no bubbles reaching the patient.
#2	Reliable Pressurized Flow (1–3 mL/min minimum)	Without gravity, flow must be actively driven. If the pressure system fails, the IV fails.
#3	Crew Autonomy & Ease of Use	Crew must prime and operate the system without ground support. Setup target: under 90 seconds.
#4	Single-Use Sterile Line with Secure Connections	Fluid-sealed connectors prevent contamination and fluid loss during connect/disconnect operations. Connectors should be color coded or numbered for easy set up without mixing up where connections should go.
#5	Weight & Volume Minimization	Every gram matters in spaceflight. The system should be as compact and lightweight as possible.
#6	NASA-STD-3001 Biocompatibility Compliance	All materials in contact with the patient must meet NASA human spaceflight standards.

> ⚠ **Priority #1 is Non-Negotiable**
> Any design that could introduce air into the patient's bloodstream will not pass the NASA review, regardless of how well it performs on other criteria. Your air-elimination strategy must be the first thing you validate in testing.

6. What You Must Deliver

Your project is organized into six design phases over the semester. Each phase requires deliverables. All deliverables must be submitted to your instructor and will be included in your NASA client presentation. ** Again- you may not be following this time-line since most of you are doing a year long project***

Phase 1 — Define (Weeks 1–2)

- Team charter with assigned roles (Project Lead, Build Lead, Test Lead, Documentation Lead)
- Problem statement: a one-paragraph written summary of the engineering challenge in your own words
- Stakeholder map identifying NASA HH&P as the client and listing their key constraints
- Initial list of 10+ questions you have about the design problem

Phase 2 — Ideate (Weeks 3–5)

- A minimum of 15 design concepts across all three subsystems: pressure/flow, air elimination, and connectors
- Evidence of methods used (e.g., sketching, mind mapping, SCAMPER, analogical thinking)
- Concept selection matrix comparing at least 5 leading concepts against the design priorities in Section 5
- Selected concept with written rationale for why it best addresses the requirements

Phase 3 — Design (Weeks 6–8)

- Annotated engineering drawings or CAD models of your selected concept
- Bill of Materials (BOM) with part names, sources, quantities, and estimated cost
- Safety review: identification of all potential failure modes and how your design addresses them
- Test plan: how will you verify each functional requirement? List one test per FR.

Phase 4 — Build (Weeks 9–11)

- Working prototype that addresses all required FRs (FR-3.1 through FR-3.3 and FR-4.1–4.2)
- Build log in lab notebook documenting key decisions made during construction
- Photograph or video documentation of prototype at each major assembly milestone

Phase 5 — Test (Weeks 12–14)

- Completed test data for all FRs in your test plan
- Flow rate test: measure actual flow rate at three settings and compare to target (±10%)
- Air elimination test: inject a known air volume, verify it does not pass through to the output
- Prime time test: time three trials of the setup process, record average
- Written analysis: which requirements did you meet? What failed? What would you do differently?

Phase 6 — Present (Weeks 15–16)

- Final slide presentation (10–15 slides) presented to NASA HH&P client
- Live demonstration of working prototype during the presentation
- Complete lab notebook with entries from every phase
- One-page team reflection: what did you learn about engineering design and space medicine?

7. Grading Rubric (If Teachers want to use this)

Your final grade is based on the following categories. Note that prototype performance (does it work?) counts for 35% — the most heavily weighted single category. Process documentation and client presentation together account for 45%, reflecting that how you work and how you communicate are as important as what you build.

Category	Weight	What NASA & Instructors Look For
Functional Requirements Met	**35%**	Does the prototype satisfy FR-3.1 through FR-3.3? Air elimination, flow rate, safety, crew autonomy.
Design Process Documentation	**25%**	Lab notebook, ideation artifacts, iteration evidence, test data, decision rationale.
NASA Client Presentation	**20%**	Phase 6 presentation quality: clarity, evidence, technical depth, response to questions.
Prototype Build Quality	**10%**	Construction quality, durability, completeness, adherence to safety rules.
Team Collaboration	**10%**	Role distribution, peer review completion, shared lab notebook contributions.

Lab Notebook Requirement

A completed lab notebook is required to receive credit in every phase. Notebooks must include dated entries, sketches or photos, test data tables, and written reflections. Entries cannot be back-filled — instructors will check timestamp metadata on digital notebooks.

8. Lab Safety Rules

All work in the lab is subject to the following rules.

Working with Fluids

- Use distilled water or saline for all IV-line
- Clean up all spills immediately; fluid on lab surfaces creates a slip hazard
- Never test with a line connected to a person. All flow tests use a simulated patient (a container or mannequin arm only)

Working with Pressure

- Pressure infusers and bulb pumps must be rated for the pressure levels used in testing

- Never exceed the maximum rated pressure of any component
- Release all pressure from the system before disconnecting any fitting

Electrical Safety (Bonus section)

- All electrical components must be inspected by the instructor before first use
- No soldering without instructor supervision and proper ventilation
- Battery-powered prototypes only during testing; no direct wall power connections without instructor approval

General Lab Rules

- Closed-toed shoes required at all times in the lab
- Safety glasses required when working with pressurized systems or cutting tools
- All tools returned to their designated location at the end of each session

9. Reference Materials & Resources

The following resources are available to your team throughout the semester:

Documents Provided

- IV Fluids Admin Scope (Merged) — the complete functional requirements document from NASA HH&P
- NASA-STD-3001, Volume 2: Human Integration Design Handbook (available from your instructor)

Key Engineering Concepts to Research

- Peristaltic pumps and pressure infusers — how they create flow without gravity
- Phase-separation filters and hydrophobic membranes — how to separate gas from liquid
- Luer-lock and fluid-sealed medical connectors — how to prevent leaks
- Flow rate measurement — using timed volume collection or electronic flow sensors
- Failure Mode and Effects Analysis (FMEA) — a structured method for identifying safety risks

Online Resources

- NASA Human Research Program: https://www.nasa.gov/hrp
- NASA-STD-3001 summary resources on the NASA Technical Standards System
- Engineering design process guidance from the Biomedical Engineering Society (BMES)

A Message from NASA HH&P

The engineers at NASA's Human Health and Performance group are genuinely interested in what you build this semester. The constraints you are working under are the same ones we face. The questions you ask and the ideas you explore may directly inform how we approach this problem for future crewed missions. We look forward to seeing your work at the Phase 6 review.

Good luck. Build something that works in space.