MECHANICAL ENGINEERING

PRODUCT DESIGN & DEVELOPMENT PROJECT REPORT

3-in-1 Solar-Operated Agricultural Sprayer

Product Design

Fig. 0.1 — Multi-view CAD renders of the 3-in-1 solar-operated agricultural sprayer

Project Type: Product Design & Development / New Product Introduction (NPI)

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Executive Summary

Conventional agricultural sprayers used across small and marginal farms in India are predominantly fuel-powered or fully manual. Both categories present practical limitations: fuel-powered units carry recurring operating costs and emissions, while manual units place a high physical burden on the operator and offer limited, inconsistent spray pressure. In regions with unreliable grid electricity, these limitations are compounded by restricted access to charging infrastructure.

This project addresses the problem through the product design of a 3-in-1 solar-operated agricultural sprayer that is capable of operating in three independent modes — solar-powered, rechargeable-battery-powered, and manual hand-pump — within a single portable backpack-style unit. The manual pump mode is retained specifically as a reliability failsafe, ensuring the sprayer remains operable even if the electrical system is unavailable or discharged.

The design integrates a 15 L HDPE tank, a 20 W solar panel, a 12 V 7.2 Ah rechargeable battery, and an electrically driven pump capable of delivering 2.0–4.5 bar spray pressure, within a target system weight of ≤8.5 kg and a target manufacturing cost below ₹4,500.

The product-design methodology followed a structured New Product Introduction (NPI) approach: requirements definition, multi-concept generation, weighted Pugh-matrix concept selection, parametric CAD modeling and assembly in Autodesk Fusion 360, interference checking, design review against requirements, Design for Manufacturing and Assembly (DFMA) evaluation, and preparation of a production-intent CAD dataset (STEP/IGES files, 2D drawings, bill of materials, and exploded views).

The report that follows documents this process end-to-end, distinguishing clearly between confirmed project inputs, design targets/assumptions, and proposed future improvements, in line with standard engineering documentation practice. Key engineering benefits anticipated from the design include reduced dependency on fossil fuel for spraying operations, improved operational uptime through the manual-pump failsafe, and a component architecture suited to low-cost, high-volume manufacturing processes such as blow molding and injection molding.

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1. Introduction, Background & Problem Statement

1.1 Agricultural Spraying Requirements

Controlled application of pesticides, fungicides, and liquid fertilizers is a core operation in crop management. The equipment used for this task must deliver liquid at a consistent pressure and droplet size so that chemical dosage is applied uniformly across the crop canopy — under-application reduces effectiveness, while over-application increases input cost and environmental load. For small and marginal landholdings, which make up a large share of Indian agriculture, the sprayer must also be portable, low-cost, and simple enough to operate and maintain without specialized technical support.

1.2 Existing Problems

Conventional sprayers used in the field generally fall into two categories, each with recognized limitations:

- **Fuel-powered (engine-driven) sprayers —** recurring fuel purchase cost and dependency on fuel availability in rural areas;
- exhaust emissions and associated air-quality/health considerations during close-range operation;
- **Manual (hand-pump) sprayers —** dependency on the operator's physical stamina, resulting in inconsistent spray pressure over a working session;
- lower achievable pressure and coverage rate compared to powered alternatives;
- **Battery-only powered sprayers —** dependency on grid charging infrastructure, which is not always reliably available in remote agricultural locations, for any electrically powered alternative;
- no operational fallback if the battery is discharged or the charging source is unavailable at the time of use.

These are general, well-documented limitations of existing sprayer categories and are presented here as the motivation for the design; no specific competitor product data or field-measured figures are claimed.

1.3 Problem Statement

> ***"Design a portable agricultural sprayer capable of operating through multiple energy sources while minimizing fuel dependency, maintaining reliable spraying capability, and remaining suitable for rural deployment."***

1.4 Need for the Proposed Product

A single-power-source sprayer inherits that source's specific failure mode: a fuel-only unit fails when fuel is unavailable, a battery-only unit fails when the battery is discharged and no charging point is accessible, and a manual-only unit is limited by operator fatigue. Combining solar charging, battery storage, and a manual pump backup within one product means that each mode compensates for the operational gap of the others. Solar charging reduces recurring dependency on grid electricity or fuel; the battery provides stored energy for operation during low-sunlight periods or evening use; and the manual pump guarantees the sprayer remains functional even in a complete electrical-system failure. This layered redundancy is the central engineering rationale for the tri-mode architecture, rather than any single mode being presented as superior in isolation.

2. Objectives, Customer Requirements & Design Specifications

2.1 Project Objectives

- Develop a multi-power (solar / battery / manual) agricultural sprayer as a single integrated product.
- Reduce dependency on fuel and on continuous grid-charging infrastructure.

- Provide a mechanical backup (manual pump) so the product remains operable during electrical-system failure.
- Improve portability through a backpack-style form factor within a defined weight target.
- Reduce long-term operating cost relative to fuel-powered alternatives.
- Design the product architecture for manufacturability (DFM) and economical component sourcing.
- Maintain a simple, serviceable assembly using standard fasteners and accessible sub-assemblies.
- Select materials appropriate to liquid storage, structural loading, and cost targets.
- Develop a complete, CAD-ready product concept suitable for downstream detailed design and prototyping.

2.2 Customer / User Requirements

The following user-facing requirements were used to guide concept generation and evaluation:

- Portability — the unit should be wearable/carryable by a single operator over a typical field session.
- Ease of operation — controls and mode-switching should not require technical training.
- Reliability — the product should remain usable even if one power source is unavailable.
- Low operating cost — reduced reliance on recurring fuel purchase.
- Easy maintenance — accessible components, minimal specialized tooling for service.
- Rural usability — must function without dependency on continuous grid electricity.
- Safety — stable carrying posture, secure electrical enclosure, safe pressure range.
- Adequate spray pressure and consistent output across a working session.
- Reasonable tank capacity suited to typical small-plot spraying sessions.

2.3 Engineering Design Specifications

Parameter	Target	Basis
Tank capacity	15 L	Project specification
Solar panel	20 W	Project specification
Battery	12 V, 7.2 Ah	Project specification
Pressure range	2.0 – 4.5 bar	Project specification
Target weight	≤ 8.5 kg	Design target
Manufacturing cost	< ₹4,500	Design target
Tank material	HDPE	Project specification
Backup system	Manual pump	Project specification
CAD software	Autodesk Fusion 360	Project specification
Reference standard	IS 6232 (considered)	Design consideration

3. Concept Development & Concept Selection

3.1 Design Concept Generation

Multiple layout concepts were generated by varying the arrangement of the major sub-systems while keeping the tri-mode power requirement fixed. Variables considered during concept generation included:

- Power-source arrangement — relative placement of solar panel, battery, and pump.
- Tank arrangement — single tank versus split/dual-chamber tank geometry.
- Pump location — integrated within the base versus a separate mounted module.
- Battery placement — internal cavity versus an external, removable battery box.
- Solar panel mounting — fixed-angle versus a hinged/foldable panel bracket for storage and transport.
- Frame configuration — load path from the tank/battery mass to the backpack straps.
- User ergonomics — strap position, carry handle placement, and center-of-gravity balance.

3.2 Three Operating Modes

Mode 1 — Solar

The 20 W solar panel supplies power to the electrical system, primarily to charge the 12 V battery when the unit is in use or at rest in daylight, allowing the pump to be driven from solar-derived energy without depleting stored battery charge.

Mode 2 — Battery

The 12 V, 7.2 Ah rechargeable battery supplies power to the electric pump when direct solar input is insufficient — for example, during low-light conditions, indoor storage areas, or early-morning/evening spraying sessions.

Mode 3 — Manual

The manual hand-pump provides a purely mechanical means of pressurizing the tank contents, independent of the electrical system, and serves as a reliability failsafe if both the solar input and battery charge are unavailable.

3.3 Weighted Pugh Matrix — Concept Selection

Three candidate layout concepts were evaluated using a weighted Pugh matrix against six evaluation criteria: cost, weight, reliability, manufacturability, energy independence, and ergonomics. Each criterion was assigned a relative weight, and each concept was scored against a datum; the weighted scores were summed to obtain a total concept score.

Criterion (Weight)	Concept 1	Concept 2	Concept 3 (Selected)
Cost (0.20)	0.60	0.80	1.00
Weight (0.20)	0.60	0.80	1.00
Reliability (0.20)	0.80	0.60	1.00
Manufacturability (0.15)	0.60	0.60	1.00
Energy independence (0.15)	0.80	0.80	1.00
Ergonomics (0.10)	0.60	0.60	0.80
Total Weighted Score	0.75	0.80	1.15

Table 3.1 — Weighted Pugh matrix concept-selection summary (criteria and scores as used in the project evaluation)

3.4 Final Concept Selection

Concept 3 was selected with a total weighted score of 1.15, ahead of the alternative concepts at approximately 0.75–0.80. This concept combined an integrated pump/battery base with a hinged, foldable solar panel bracket, giving the best balance across cost, weight, and manufacturability while still meeting the reliability and energy-independence criteria at the top score band. The selected architecture forms the basis for all subsequent CAD, material, and manufacturing decisions described in this report.

4. Product Architecture & CAD Design

The selected concept was developed into a fully defined, parametric CAD assembly in Autodesk Fusion 360. The major functional components, their role, key design considerations, and manufacturing implications are summarized below.

4.1 Major Components

Component	Function	Key Design Consideration	Manufacturing
15 L storage tank	Holds the liquid to be sprayed	Wall thickness/ribs for blow-molded HDPE; sized to 15 L target	Blow molding
Structural / support frame	Carries mounted-component loads to backpack straps	Load path from tank + battery mass to strap points; weight target	Sheet metal / extrusion
Solar panel mounting	Positions the 20 W panel; supports it in transport	Hinged bracket folds panel flat against tank for storage	Sheet metal/extrusion, fasteners
Battery housing	Encloses and protects the 12 V, 7.2 Ah battery	Sized to battery; serviceable; sealed against liquid ingress	Injection molding
Pump system (electric)	Pressurizes tank in solar/battery modes	Sized to 2.0–4.5 bar target; accessible for service	Bought-out component
Manual pump mechanism	Mechanical pressurization, electrical-independent	Ergonomic lever; reliable seal for repeated actuation	Bought-out + custom mounting
Spray hose	Carries pressurized liquid to the spray lance	Flexible routing; abrasion/chemical resistance	Purchased component
Spray lance	Extends operator's reach to crop area	Length/grip for standing or walking operation	Purchased/assembled
Spray nozzle	Atomizes and directs spray pattern	Sized to operate across 2.0–4.5 bar	Purchased component
Control / switching	Operator selects/isolates power path	Simple layout; splash-sealed enclosure	Purchased hardware + mounting
Backpack / handle / support	Carries unit on back or by handle	Strap position tuned for load balance	Molded/fabric assembly, fasteners
Fasteners & mounting hardware	Secures sub-assemblies to one another	Standardized sizes to simplify assembly/sourcing	Standard bought-out hardware

4.2 CAD Workflow

Component and assembly development followed a structured CAD workflow, illustrated in Fig. 4.1:

Requirements → Concept → Component Modeling → Assembly → Interference Check → Design Review → Manufacturing Considerations → Final CAD Dataset

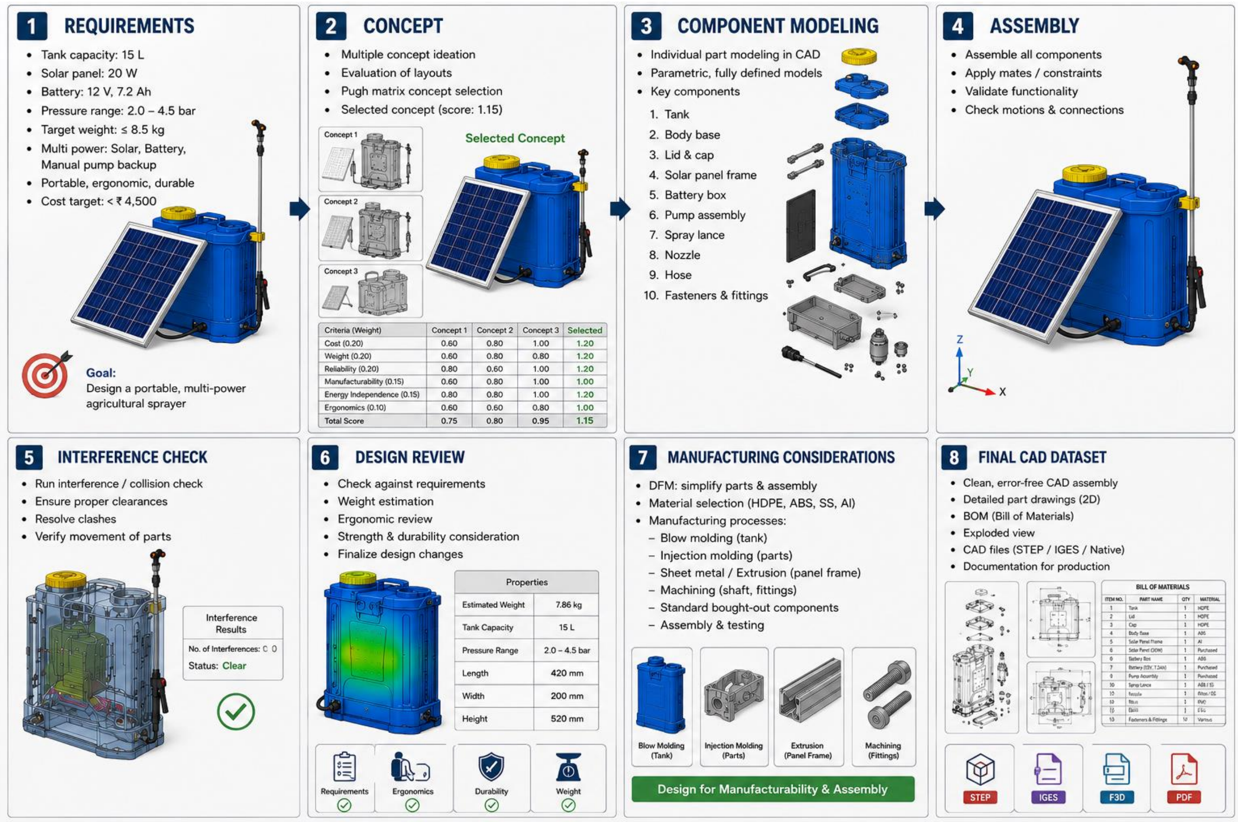

Fig. 4.1 — CAD workflow followed for the 3-in-1 solar-operated agricultural sprayer, from requirements definition through to the final CAD dataset

Interference checking on the completed assembly returned zero clashes across the modeled components, and the assembly was reviewed against the Section 2.3 specifications for weight, dimensional envelope, ergonomics, and durability considerations prior to being carried into the manufacturing-consideration stage.

5. Material Selection & Design for Manufacturing

5.1 Material Selection

Tank — HDPE (confirmed project material)

- Low density relative to metals, keeping the tank's contribution to overall system weight low.
- Strong chemical resistance to common agricultural liquid formulations.
- Good corrosion resistance for long-term liquid storage compared to uncoated metals.
- Well suited to blow molding, a mature, economical process for hollow liquid-storage containers.

For the remaining components, materials are distinguished below as either confirmed project inputs or design-stage recommendations; the latter should be treated as proposed values pending detailed design and supplier confirmation.

Component	Material	Status
Tank	HDPE	Confirmed project material
Body base / housings	ABS / HDPE	Recommended / proposed
Structural frame / brackets	Aluminium or mild steel (sheet/extrusion)	Recommended / proposed

Component	Material	Status
Fasteners	Stainless steel (standard hardware)	Recommended / proposed
Spray lance	ABS / PVC composite	Recommended / proposed
Hose	Reinforced PVC / rubber	Recommended / proposed (purchased component)

5.2 DFM Analysis

The product architecture was evaluated for economical, high-volume production using standard Design for Manufacturing (DFM) principles:

- Reduction of unnecessary part count by combining structural and enclosure functions where feasible.
- Use of standard, commercially available fastener sizes rather than custom hardware.
- Simplified joint types (snap-fit / standard threaded fasteners) in place of specialized joining methods.
- Assembly sequencing that keeps sub-assemblies (battery box, pump module, solar bracket) independently accessible for service.
- Geometry choices (draft angles, uniform wall sections on the tank) suited to molding processes.
- Minimized machining, reserved only for fittings/shafts where molded or extruded tolerances are insufficient.
- Modular component replacement — battery, pump, and nozzle are treated as independently replaceable sub-assemblies.

5.3 Manufacturing Processes

Component	Proposed Process
Tank	Blow molding
Body base, lid/cap, housings	Injection molding
Solar panel frame / structural bracket	Sheet-metal fabrication or extrusion
Shafts, selected fittings	Machining
Pump, hose, nozzle, battery, solar panel	Standard bought-out components
Final assembly	Manual / semi-automatic assembly and functional testing

6. Working Principle & System Integration

Solar Mode

Solar Panel → Charging / Power Management → Battery / Electrical System → Pump → Spray Nozzle

Energy captured by the 20 W solar panel is routed through the charging/power-management path to the electrical system, from where the pump draws power to pressurize and deliver liquid through the nozzle.

Battery Mode

Battery → Electrical Pump → Pressurized Liquid → Hose → Nozzle

The 12 V, 7.2 Ah battery supplies the electric pump directly, which pressurizes the tank contents and delivers liquid through the hose to the nozzle for spraying.

Manual Mode

Manual Pump → Mechanical Pressure Generation → Liquid Flow → Spray Nozzle

Operator-actuated lever motion on the manual pump generates mechanical pressure within the tank directly, independent of the electrical system, driving liquid flow to the nozzle.

6.1 System Integration

The complete product integrates four sub-systems around a common tank and pressure-delivery path:

- Mechanical — tank, frame, manual pump, spray lance, and carrying structure.
- Electrical — solar panel, battery, wiring, switching, and electric pump.
- Fluid — tank, hose, nozzle, and the shared pressurized-liquid path used by both electric and manual modes.
- User interface — mode-selection switch and manual-pump handle, kept simple and intuitive per the Section 2.2 requirements.

Because the electric pump (solar/battery modes) and the manual pump share a common tank and downstream hose/nozzle path, the fluid delivery sub-system does not need to be duplicated for each power mode — only the pressurization method changes.

6.2 Reliability Through Redundant Power Paths

Each of the three modes provides pressurization through an independent path (solar-charged electrical, battery-stored electrical, and purely mechanical). This means a failure or unavailability in one path — for example, a discharged battery or an overcast day limiting solar input — does not render the product unusable, since the manual pump remains available as a mechanical fallback at all times.

7. Design Analysis, Validation & Testing Plan

The following outlines the validation approach proposed for this product ahead of physical prototyping and production release. Where results are not yet available, this is stated explicitly rather than assumed.

7.1 Mechanical Validation

- Structural integrity of the frame under combined tank/battery load.
- Frame loading under the carried, filled-tank condition.
- Tank mounting security under normal walking/field motion.
- Fastener strength at frame-to-tank and bracket joints.
- Vibration resistance during transport and field use.

7.2 Fluid-System Validation

- Leakage testing at all hose, fitting, and tank-outlet joints.
- Pressure testing across the 2.0–4.5 bar target range.
- Flow-rate testing at the nozzle under representative pressure.
- Spray-pattern evaluation for uniformity of coverage.
- Nozzle performance across the operating pressure band.

7.3 Electrical Validation

- Battery operating duration under continuous pump load.
- Solar charging performance under representative daylight conditions.
- Pump power consumption at rated pressure.
- Electrical safety of the switching arrangement and battery enclosure.

7.4 Ergonomic Validation

- Overall carried weight against the ≤8.5 kg target.
- Carrying comfort over an extended field session.
- Handle and strap position relative to the loaded center of gravity.
- Accessibility of components (battery, pump, manual-pump handle) during use.
- General operator usability of the mode-selection interface.

7.5 Design Validation Matrix

Requirement	Validation Method	Expected Outcome	Status
Tank capacity (15 L)	Volumetric check on CAD model / molded part	Meets 15 L target	Proposed / To Be Tested
Pressure range (2.0–4.5 bar)	Bench pressure test, electric & manual modes	Delivers within target band	Proposed / To Be Tested
System weight (≤8.5 kg)	Weigh assembled unit	At or below target	Proposed / To Be Tested (CAD estimate: 7.86 kg)
Leak-free fluid path	Static & dynamic leak test	No leakage at rated pressure	Proposed / To Be Tested
Solar charging function	Daylight charging trial with multimeter logging	Battery charge increases under sunlight	Proposed / To Be Tested
Manual-mode failsafe	Operate with battery disconnected	Spray delivered via manual pump only	Proposed / To Be Tested
Structural integrity	Static load test on frame	No yielding at rated load	Proposed / To Be Tested
Ergonomic carry comfort	Wearer trial over a field-length session	Acceptable comfort rating	Proposed / To Be Tested

The 7.86 kg figure shown above is a CAD-software mass estimate derived from the modeled geometry and assigned materials, generated during the design-review stage of the CAD workflow (Section 4.1) — it is a modeled estimate, not a measurement from a physical unit.

7.6 Role of Prototype Testing

A physical prototype build is the recommended next step following this design-stage report. Prototype testing would be used to confirm the CAD-based weight and pressure estimates against physical measurement, validate leak-free operation across all three modes, and surface any DFM or assembly issues not visible in the CAD model, before committing to production tooling.

8. Cost, NPI, Advantages & Future Development

8.1 Cost Considerations

The design targets a manufacturing cost below ₹4,500. This is a target used to guide component selection and architecture decisions (e.g., favoring molded parts and standard bought-out hardware over custom-machined components) rather than a costed bill of materials. The principal cost drivers for a product of this type are expected to be:

- Battery (12 V, 7.2 Ah)
- Solar panel (20 W)
- Electric pump assembly
- Tank (blow-molded HDPE)
- Structural frame and brackets
- Nozzle and spray lance
- Hose
- Electrical components (switching, wiring)
- Fasteners
- Assembly labor

8.2 NPI Methodology

The project followed a New Product Introduction (NPI) structure appropriate to an early-stage product-design exercise:

Requirement Definition → Concept Development → Concept Selection → Detailed Design → CAD Assembly → DFM Review → Prototype → Testing → Design Validation → Production Readiness

This report covers the stages through DFM review and defines the validation plan for the prototype/testing stages that follow; the Prototype through Production Readiness stages are proposed next steps rather than completed work.

8.3 Product Advantages

- Multi-power operation across solar, battery, and manual modes.
- Reduced dependency on fuel for spraying operations.
- Manual-pump backup ensures continued operability during electrical-system failure.
- Renewable-energy (solar) integration reduces reliance on grid charging.
- Backpack-style portability suited to field use.
- Potential for lower operating cost relative to fuel-powered alternatives, subject to prototype validation.
- Simple maintenance through modular, accessible sub-assemblies.
- Architecture suited to rural deployment where charging infrastructure is inconsistent.

8.4 Future Scope

The following are proposed future concepts for subsequent design iterations, not features of the current design:

- Lithium-ion battery in place of the current battery chemistry, for reduced weight.
- Improved solar charging system with higher-efficiency panel and MPPT charge control.
- Dedicated Battery Management System (BMS) for charge/health monitoring.
- Automatic pressure control / regulation.
- Digital pressure display for the operator.
- IoT-based remote monitoring of usage and battery state.

- Flow-rate monitoring at the nozzle.
- Lightweight frame redesign using topology-optimized geometry.
- Improved ergonomic harness / load-distribution system.
- Quick-change nozzle system for different spray patterns.
- Smart charging controller with adaptive solar/battery balancing.

9. Conclusion, Engineering Learnings & Interview Summary

9.1 Conclusion

This project demonstrates a complete early-stage product-development cycle for a 3-in-1 solar-operated agricultural sprayer, carried through from requirements definition to a production-intent CAD dataset. The work integrates core product-design competencies — structured concept generation and weighted concept selection, parametric CAD modeling and assembly in Autodesk Fusion 360, interference checking and design review, material selection distinguishing confirmed inputs from proposed choices, DFM evaluation for economical manufacturing, and NPI-aligned process thinking — applied to a multi-disciplinary system spanning mechanical, electrical, and fluid sub-systems. The result is a coherent, manufacturable product architecture with a clearly defined validation plan for the prototype stage that follows.

9.2 Engineering Skills Demonstrated

Skill	Application in Project
Product Design	Complete product architecture across tank, frame, power, and fluid sub-systems
CAD	Parametric 3D modeling and full assembly in Autodesk Fusion 360
DFM	Manufacturability evaluation and process selection (blow molding, injection molding, etc.)
Material Selection	HDPE tank selection; distinguishing confirmed vs. proposed materials
Concept Selection	Weighted Pugh matrix across six evaluation criteria
NPI	Structured product-development lifecycle, requirements through to CAD dataset
Cost Engineering	Design decisions guided by a sub-₹4,500 manufacturing cost target
System Integration	Coordinated mechanical, electrical, and fluid sub-system design
Problem Solving	Multi-power reliability architecture addressing single-source failure modes

9.3 Key Engineering Learning

The project reinforced how early architectural decisions — such as selecting a tri-mode power path over a single-source design — directly shape downstream outcomes in weight, cost, and manufacturability, and why a structured, criteria-weighted concept-selection method (rather than intuition alone) produces a more defensible design decision. It also reinforced the discipline of clearly separating confirmed project inputs, design assumptions, and proposed future work throughout engineering documentation, which is essential both for engineering integrity and for presenting the work credibly in a professional or interview setting.

— End of Report —