Additive Manufacturing and Its Potential for Aircrafts and the AIAA DBF Competition

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The University of Memphis AIAA Senior Design team has created plans relating to the design, manufacturing, and testing of an alternative solution for the 2024-2025 Design, Build, Fly (DBF) competition. Four specialized sub-teams—Electronics, Mechanical, Flight, and Manufacturing—collaborated to fulfill the requirements set for the competition, including carrying multiple "fuel tanks," completing several laps around the track, and releasing an autonomously landing lightweight glider (the X-1). This design will prioritize agility, structural integrity, and modularity. A Clark Y airfoil with a 3-degree angle of attack and a 63" wingspan has been selected to provide an optimal lift-to-drag ratio. Trade studies support the decision to carry two fuel tanks, balancing added weight, aerodynamic performance, and structural considerations. The largest departure from the initial preliminary design and previous designs comes in the manufacturing of the mothership. The team has researched, tested, and will 3D print the entire mothership in sections utilizing PLA, foaming LW-PLA, and TPU. The X-1 test vehicle will have a delta wing construction and be manufactured out of foam. These manufacturing practices along with the selected components should allow for a relatively low flight weight even with the full payload attached. In the end, the aircraft is projected to have an overall flight weight of 3.6kg, a stall speed of 22 mph, and a level speed of 60 mph.

I. Introduction

The AIAA Design/Build/Fly (DBF) competition is an annual event that challenges university teams to design, manufacture, and test a remote-controlled aircraft capable of executing specific mission tasks. The competition encourages innovative thinking, requiring participants to balance aerodynamics, structural integrity, payload capacity, and flight efficiency while adhering to strict design constraints. The University of Memphis' mechanical engineering senior design team, MECH Men, is taking an engineering-driven approach, incorporating additive manufacturing, detailed trade studies, and iterative design refinements to develop a new way to produce a competitive aircraft.

The 2024-2025 DBF competition presents a unique set of challenges focused on payload transport, high-speed maneuverability, and the deployment of an autonomous glider. The mothership must carry multiple fuel tanks, complete laps efficiently, and successfully release the X-1 test vehicle, which will autonomously glide to a designated landing zone [1]. These requirements demand a design that is lightweight yet structurally robust, capable of handling high speeds while maintaining precise control. Achieving these objectives involves selecting an optimal

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airfoil, distributing weight efficiently, and ensuring the aircraft withstands the forces experienced during takeoff, flight, and landing.

To meet the performance goals of the competition, the team selected the Clark Y airfoil, a well-documented aerodynamic profile known for its high lift-to-drag ratio and predictable stall characteristics. With a 63-inch wingspan and a three-degree angle of attack, the Clark Y provides the necessary lift while keeping drag to a minimum. The aircraft's design also incorporates a taildragger landing gear configuration, chosen after evaluating various options based on weight efficiency, manufacturability, and stability. This layout reduces complexity, saves weight, and provides better clearance on the underside on takeoff and landing, making it an ideal choice for the team's design and carrying the glider mounted below.

One of the most critical trade studies conducted focused on determining the optimal number of fuel tanks to carry during competition flights. Several configurations were analyzed based on their impact on weight distribution, aerodynamic efficiency, and structural integrity. After extensive evaluation, the team decided on a two-tank configuration, which provided the best balance between maximizing mission score and maintaining stable flight characteristics. Carrying two tanks ensures that the aircraft operates at peak efficiency without becoming too heavy or aerodynamically inefficient. The placement of these tanks, along with the attachment of the X-1 glider beneath the fuselage, required careful design considerations to maintain stability during flight and ensure smooth deployment of the glider.

A significant innovation in the team's approach is the extensive use of additive manufacturing for the construction of the aircraft's structure. The mothership is 3D printed in sections using PLA, LW foaming PLA, and TPU, with carbon fiber rods and tubes providing additional reinforcement. This method allows for rapid prototyping, enables design flexibility, and facilitates the production of complex components that would be difficult to manufacture using traditional techniques. Additive manufacturing has played a crucial role in producing light yet structurally sound components, allowing for intricate geometries, such as integrated servo mounts and payload latches. However, this approach also presents challenges, including material brittleness and structural bonding issues, which the team has addressed through iterative testing and process refinements.

Predictions for flight performance were calculated using fundamental aerodynamic equations for lift and drag. With a target takeoff speed of approximately 22 mph, the aircraft is designed to achieve liftoff efficiently and maintain a maximum speed of 60 mph under competition conditions. The X-1 glider, built from lightweight foam and designed with a delta-wing configuration, is engineered to descend stably after being released from the mothership mid-flight. Ensuring a smooth release mechanism and maintaining stability during this maneuver is critical for mission success.

Throughout the design process, the team followed an iterative engineering approach, beginning with preliminary calculations and conceptual sketches before moving on to CAD modeling, prototype testing, and computational simulations. Wing tunnel simulations and flight tests helped validate aerodynamic efficiency, while structural analysis ensured that the aircraft could withstand operational stresses. Testing also played a key role in refining the payload release mechanism, as minor adjustments were required to ensure that the X-1 separated cleanly from the mothership. Every test, whether conducted through simulations or real-world prototype flights, provided valuable data that guided refinements to the design.

With deadlines approaching, the team is preparing for full-system integration tests to validate the aircraft's ability to carry the required payload, execute stable high-speed flight, and release the X-1 glider successfully. These tests will focus on evaluating takeoff performance with the two fuel tanks attached, ensuring that the aircraft can handle the additional weight while maintaining maneuverability. Further adjustments will be made based on test flight data, with rapid redesigns made possible through the team's use of 3D printing for component modifications. The team aims to have a fully optimized aircraft capable of performing consistently under competition conditions.

This introduction sets the stage for the detailed analysis that follows in the report. The sections ahead will discuss the aircraft's aerodynamic properties, structural design, propulsion system, and avionics in greater depth, presenting the engineering justifications behind each decision. The report will also detail the manufacturing process, including how additive manufacturing techniques were integrated into the design workflow. Finally, the results of flight testing and performance evaluations will be presented to assess the aircraft's potential readiness for competition. Through a structured and methodical approach, the team is confident in delivering a design produced in a new way that meets the demands of the 2024-2025 AIAA DBF competition.

II. Design

For the mothership, the design features a Clark-Y airfoil for high coefficients of lift at lower velocities. A 63” wingspan allows for a large wing area, providing a higher lift force. The fuselage and wings will be 3D printed and reinforced with Carbon fiber rods, ensuring structural integrity. 2 external “fuel tanks” weighing 1 pound each will be attached on either side of the fuselage using a simple latch, and the glider will be attached to the underside of the fuselage using a “bomb drop” mechanism that will release the glider when the programmed button is pressed on the controller. A tail dragging landing gear was selected due to its ability to accommodate the glider being attached underneath the fuselage.

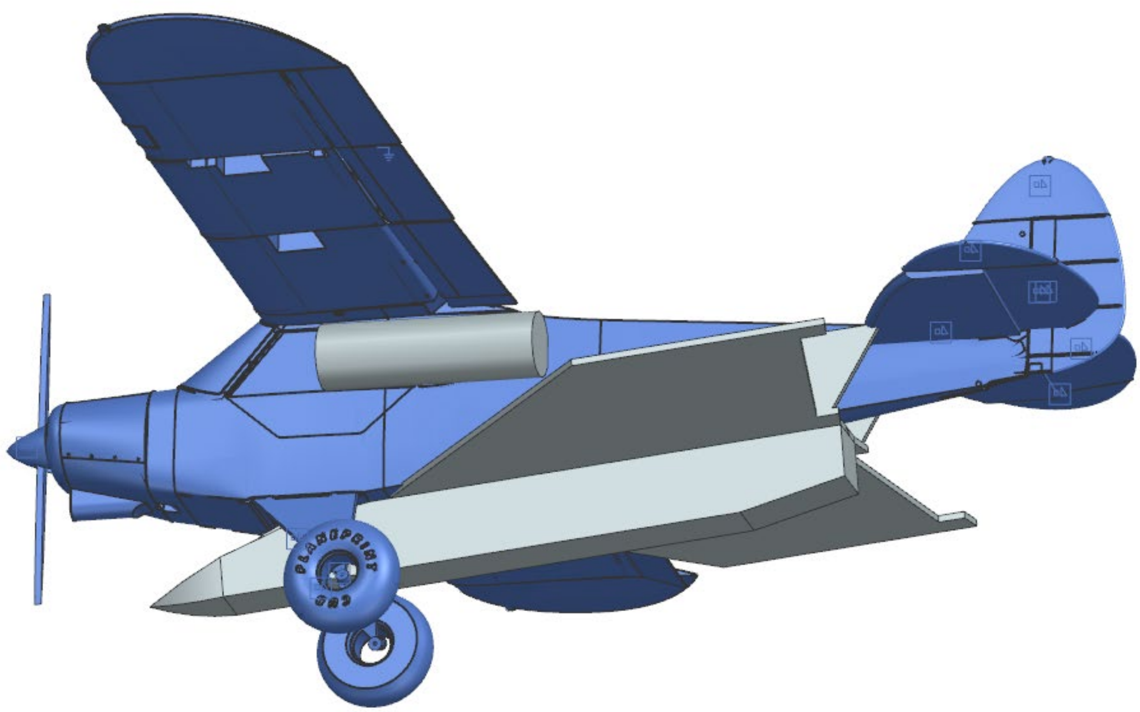
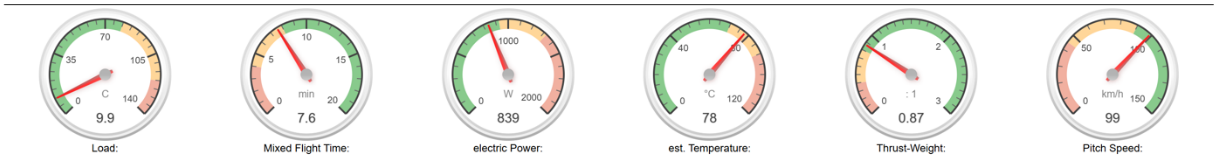


Fig. 1: 3D CAD Configuration of Mothership, Tanks, and Glider

Calculations for the lift and thrust were made to ensure the ability of the full configuration to achieve liftoff. Using the lift force equation for any object submerged in a fluid and isolating the speed value while setting the lift force equal to the weight of the aircraft, the stall speed value can be determined. Knowing the stall speed, that value can be used in the drag force equation to determine the drag force at takeoff. The thrust provided by the propeller must be higher than that value. It is worth noting that these calculations consider just the airfoil with the weight of the aircraft, meaning that there are factors that will make the coefficient of lift lower and the coefficient of drag higher than in this ideal case. To account for this, a motor was selected that produces a thrust that is higher than the value determined through these equations. To accompany these preliminary calculations, a simulation was run to determine an estimate of how the aircraft will perform with the purchased equipment.



Remarks:

Battery	
Load:	9.94 C
Voltage:	14.28 V
Rated Voltage:	14.80 V
Energy:	88.8 Wh
Total Capacity:	6000 mAh
Used Capacity:	5100 mAh
min. Flight Time:	5.1 min
Mixed Flight Time:	7.6 min
Weight:	684 g
	24.1 oz

Motor @ Optimum Efficiency	
Current:	42.00 A
Voltage:	14.28 V
Revolutions*:	11457 rpm
electric Power:	599.9 W
mech. Power:	507.2 W
Efficiency:	84.5 %

Wattmeter readings	
Current:	59.65 A
Voltage:	14.28 V
Power:	851.8 W

Motor @ Maximum	
Current:	59.65 A
Voltage:	14.07 V
Revolutions*:	10842 rpm
electric Power:	839.0 W
mech. Power:	701.3 W
Efficiency:	83.6 %
est. Temperature:	78 °C
	172 °F
Rm	31.1 mΩ

Thermal Propagation				
5	11	23	35	s
46	59	71	76	°C
115	138	160	168	°F

Propeller	
Static Thrust:	3279 g
	115.7 oz
Revolutions*:	10842 rpm
Stall Thrust:	- g
	- oz
avail.Thrust @ 0 km/h:	3279 g
avail.Thrust @ 0 mph:	115.7 oz
Pitch Speed:	99 km/h
	61 mph
Tip Speed:	623 km/h
	387 mph
specific Thrust:	3.91 g/W
	0.14 oz/W
n100W:	5839 rpm
n10N:	6232 rpm

Total Drive	
Drive Weight:	1055 g
	37.2 oz
Power-Weight:	235 W/kg
	107 W/lb
Thrust-Weight:	0.87 : 1
Current @ max:	59.65 A
P(in) @ max:	882.8 W
P(out) @ max:	701.3 W
Efficiency @ max:	79.4 %
Torque:	0.62 Nm
	0.46 lbf.ft
Climb Capacity:	2604 m
	8543 ft

Airplane	
All-up Weight:	3750 g
	132.3 oz
Wing Load:	88.1 g/dm²
	28.9 oz/ft²
Cubic Wing Load:	13.5
est. Stall Speed:	45 km/h
	28 mph
est. Speed (level):	96 km/h
	60 mph
est. Speed (vertical):	- km/h
	- mph
est. rate of climb:	8.5 m/s
(~35...40°)	1665 ft/min

Fig. 2: Simulated Flight Values, eCalc [2]

In the simulation, the only point of serious concern is the temperature of the motor at its maximum power draw. The plane should not require the maximum power draw of the motor, so the temperature concern should be avoided in a full flight. When the test flight is performed, adjustments can be made based on any measured variance between the real flight and the simulation. Otherwise, the flight time, thrust, pitch speed, load, and power draw are all within an acceptable range. To fully confirm the validity of this design, extensive tests on the physical specimen will be necessary.

This design was the culmination of multiple iterations and options over multiple months. The original iteration involved a balsa wood frame and had 4 tanks mounted underneath the wings. This design was ultimately determined to be ineffective due to the balsa wood being very time-consuming to manufacture to the necessary specifications of the original design. This original design had a much greater focus on the amount of weight the plane would be able to carry but is much less efficient to manufacture and weighs more than the current iteration.

Overall, the design is effective at optimizing for the goals outlined. The overall weight of the plane is low, and structural integrity allows for the extra weight in the form of external fuel tanks to be added. This will optimize the mission objective to add as much weight to the plane as possible without compromising the manufacturability of the plane. The choice of landing gear and size of the fuselage allows for simple mounting of the glider with an acceptable level of clearance. This design ultimately trades off having 4 fuel tanks for the sake of having ease of manufacturing and assembly while minimizing the weight of the plane itself compared to the weight of a balsa wood frame. Due to the PLA being a weaker material in bending compared to balsa wood, the number of fuel tanks to be reduced to two to ensure the structural integrity of the plane remains. The mounting location for the tanks was also moved from the original location of being under the wings to account for the wings being weaker in bending with the PLA compared to balsa wood.

One of the most important aspects of the current design was the implementation of 3D printing to streamline the manufacturing of the final product. This method allowed for a swift realization of the design resulting in extra time to troubleshoot and account for various risks during assembly. Being able to spend extra time addressing issues during assembly is what allowed the plane to be realized within the allotted timeframe without delays or changes in scope of the project. The original balsa wood design would likely have been impossible to implement in the same timeframe under the same constraints.

III. Additive Manufacturing

A key turning point in this project was the decision to 3D print the mothership's primary structure instead of using a traditional balsa wood frame covered with Monokote. Early on, the team realized that balsa wood, while lightweight, can be time-intensive and often requires a significant level of craftsmanship to ensure precise cuts, proper joints, and a consistent finish. More importantly, making design revisions or repairing crash damage in a balsa wood build is laborious. It frequently demands re-fabricating entire sections and re-covering them to preserve aerodynamic smoothness. In contrast, additive manufacturing allowed rapid iteration: once the CAD models were finalized, we could produce the fuselage, wings, and other critical components layer by layer, eliminating much of the manual labor associated with wood construction. If a printed piece was found to be flawed after assembly, due to a design oversight or a mishap during gluing, we could simply remove the faulty section with an Exacto knife, load new filament, and reprint most components in under an hour.

The team used three distinct filament types to address specific engineering requirements. eSun ePLA-LW, a foaming PLA variant, comprises the bulk of the airframe, including the fuselage, wing panels, and tail surfaces. During printing, ePLA-LW expands at higher temperatures, resulting in a lightweight, foam-like core with roughly 6% infill. This composition significantly reduces overall weight without sacrificing too much rigidity, making it ideal for large sections that must remain airborne yet structurally sound. Considerations, estimations, and use cases were based on the materials specifications found in the data sheet [3]. The second material, Polymaker Polylite PLA Pro, was printed at 100% infill to reinforce high-stress components—wing spars, motor mounts, and certain fuselage junctions, for instance—where maximum strength was paramount thanks to its specifications [4]. Finally, Polymaker TPU95 (A95 TPU) was employed for flexible parts such as gaskets, shock absorbers, and wheels, ensuring that these components could absorb vibration and withstand repeated impacts during landings. This TPU was selected as it had considerable upsides in both its flexural and elongation properties [5]. Using a softer, more elastic material like TPU helped protect the more rigid PLA elements from damage when the aircraft rolled out on uneven surfaces or experienced hard landings.

All slicing was done in Orca Slicer, which provided granular control over temperatures, infill densities, layer heights, and print speeds for each material. Orca Slicer was selected for its intuitive interface and powerful features such as variable layer thickness (which can help save filament and time on less critical areas) and the ability to finely tune foaming parameters for ePLA-LW. While the Creality K1C printer's core XY architecture allows for very high acceleration and travel velocities, the team still tailored print speeds to each filament's needs. The foaming PLA and standard PLA Pro could be pushed to higher speeds without significant loss of accuracy, but TPU required more cautious settings to avoid stringing and extrusion errors common to flexible filaments. Additionally, we relied on a textured build plate for improved first-layer adhesion; TPU, in particular, clings well to such surfaces but remains easier to remove than on smooth glass or metal plates. A standard 0.4 mm nozzle was used to balance print resolution with throughput, though larger nozzles (0.6 mm or 0.8 mm) might have further reduced print times if lower resolution were acceptable.

Over the course of about a week, the project accrued 72 hours of print time for the mothership's various sections. Despite the complexity of the geometry—particularly where servo pockets, wire channels, and carbon-rod reinforcements were integrated into the design—only one filament jam and two failed prints occurred. The jam was quickly traced to a minor temperature fluctuation, and the failed prints were resolved by fine-tuning retraction settings and layer adhesion temperatures. This low failure rate proved that consistent calibration and frequent monitoring of the printer settings yielded reliable parts for what might otherwise be considered an ambitious project. Team members periodically checked each print run to verify correct bed adhesion, confirmed extruder temperature stability, and adjusted any bridging or overhang settings that might need refinement.

Once all sections were printed, assembly progressed over about five days, requiring an estimated 50 person-hours in total. Critical steps included inserting carbon rods into pre-modeled channels within the wings and fuselage, gluing these rods into place for added bending stiffness, and ensuring that mating surfaces aligned properly before adhesives cured. Epoxy resin was typically used for bonding high-stress components, such as wing spars and motor mounts, while cyanoacrylate (CA) glue provided quick bonds for smaller mating surfaces or lightly loaded joints. Components such as servo mounts, tail surfaces, and landing gear brackets were printed with built-in holes or registration marks that simplified alignment, further speeding up assembly. By the end of this stage, the mothership's 3D-printed structure weighed around 2.65 kg—a competitive figure for a 63-inch wingspan aircraft, especially one carrying additional payloads in the form of fuel tanks and an underside-mounted glider. The structure was split into multiple sections (fuselage halves, wing segments, etc.) to fit the printer's build volume and to facilitate transportation to and from the field.

The cost of this additive manufacturing approach remained manageable. Roughly $90 was spent on filament—divided among TPU, PLA Pro, and ePLA-LW—and another $90 went toward carbon rods, steel wire, and various fasteners. In total, $180 covered the bulk of structural materials, aligning closely with or even under the price range of a comparable balsa build once you factor in the cost of wood, covering film, adhesives, and potential replacement materials. Additionally, the team maintained sealed storage containers with desiccant packs for more hygroscopic filaments like TPU and foaming PLA, preserving print quality over multiple weeks of production.

Beyond cost-effectiveness, one of the standout advantages of additive manufacturing was the capacity for modular fixes and iterative improvements. During the first test flight, the left wingtip sustained damage in a rough landing. Rather than undertaking a time-consuming, delicate repair, the team simply used an Exacto knife to remove the compromised section and printed a replacement. This same capability also applied to design modifications: if flight tests or simulations revealed that a part was understrength, needed better aerodynamics, or should fit differently with neighboring components, the CAD model could be rapidly updated and reprinted. This level of adaptability was crucial to meeting tight deadlines and ensuring that the aircraft continued to evolve alongside test results and mission requirements. By contrast, a similar mistake in a balsa frame would generally require a more extensive rebuild, often delaying subsequent test flights.

Nevertheless, using 3D-printed PLA elements does introduce certain limitations. PLA, though easily printable, can be brittle under extreme bending loads, and it has a relatively low glass transition temperature, potentially affecting performance in high-heat environments. To mitigate these drawbacks, the team added carbon rods and steel wire reinforcements in strategic locations, such as along the wing spars and at major fuselage joints. Additionally, by employing PLA Pro for key load-bearing parts, we improved strength while maintaining the material's favorable printing characteristics. Finally, the flexible TPU parts—particularly the wheels, shock absorbers, and various gaskets—helped absorb shocks and protect the PLA structures, reducing the risk of stress cracks or sudden breaks during landings. The team also paid attention to potential warping or layer adhesion issues in longer prints, using proper bed temperatures and occasionally adding thin support walls or brims for tall, narrow parts.

All in all, the additive manufacturing route aligned well with the overarching goals of the 2024-2025 AIAA DBF competition. By leveraging the core XY speed of the Creality K1C, customizing slicer settings for each filament type, and benefiting from rapid reprint possibilities, the team maintained an iterative design process that quickly responded to assembly errors and flight test findings. Compared to the original balsa wood plan, this shift in production strategy not only saved time but also facilitated more intricate design features—like integrated servo compartments, pre-formed channels for carbon rods, and latch mechanisms for external tanks and the glider. With the successful completion of these printed sections, the team stands poised to fine-tune the mothership's design further, confident in the knowledge that any necessary modifications or repairs can be done swiftly and efficiently. As the competition approaches, the ease of replacing or upgrading parts—particularly those that may experience fatigue or stress during repeated flights—remains a critical advantage that could prove decisive in ensuring reliable performance across multiple sorties.

IV. Outcome and Conclusion

As stated, the components of the aircraft took 7 days to print. While the aircraft itself took just over a week to assemble. The assembly was largely successful with only a few roadblocks:

1. Support rods for the wing struts were cut to the incorrect length and required reprinting of the strut components.
2. Sections of the thin foam frame suffered damage during assembly, which required tape to retain structural integrity of the airfoil.
3. Servo motors failed to calibrate and needed to be rewired after troubleshooting. Flaps, rudder, and elevator failed to reach the required displacements and needed recalibration and new programming.

Each roadblock was met with a timely solution to stay on track for our timeline. Team members worked up to 9 hours a day to ensure project completion.

The aircraft's manufacturing was successful, with test flights permitting it to get in the air with minimal runway space. Further flight tests will allow for testing how the aircraft responds to additional weight from the tanks, as well as maneuverability with the glider attached. Further testing will utilize a larger runway space, to allow more time to gain and retain control of the aircraft before takeoff.

Additive manufacturing had both positives and drawbacks to the overall production of the aircraft. Positives include speed of production and relatively low effort compared to balsa wood constructions. Additive manufacturing and 3D printing also allowed easier production of bends, wide corners, and would allow us to “imprint” sections of the aircraft with locations for screw and bolt installation. Despite this, the material and grain made the chunks very fragile during assembly, only truly strong after assembly. This was perceived as the only major downside, with the benefits of time and money saved outweighing this negative.

Fig. 3: Weight of Mothership (2.65 kg, Without Glider and Tanks)

After weighing the aircraft, the team used all updated information in eCalc to calculate flight time with the battery, max altitude, stall speed, and thrust to weight ratio. As seen in fig. 2, the aircraft was calculated to be able to lift off with a minimum speed of 22 mph. This speed is easily achievable with the selected battery and propeller. The aircraft’s thrust to weight ratio is too low to allow for a direct vertical climb, but the aircraft has the capability to climb at a rate of 1665 ft/s at an angle between 35 to 40 degrees.

Fig. 4: Completed Mothership

In the end, the airframe remains strong. Despite damage and repairs, the aircraft was able to reach takeoff speed and get off the ground without any major issues. Any section that sustained damage was able to be fixed quickly thanks to the modularity and ease of printing. Further flight practice will demonstrate how the aircraft would have performed at the AIAA competition in Arizona.

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