Sparky Flapjack: Electric Aircraft Design Inspirations from the Vought V-173

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This paper presents a design study of electric personal aircraft concepts inspired by the Vought V-173, the famous "Flying Pancake" of late WWII. With its incredible slow flight and short field capability, this innovative design concept may point towards an aircraft suitable for the emerging "Pocket Airport" concept. The paper presents four modern concepts that could offer remarkable capabilities. All use electric propulsion, novel aerodynamics, and integrated composite construction. Four-seater and two-seater concepts have a separate crew cabin underneath the wing allowing for normal entry, unlike the V-173. Another two-seater version was designed with the cabin integrated with the wing root as in the V-173. A recreational one-person "mini" version was also designed with a prone pilot position on top of the wing.

Nomenclature

AOA	= Angle of Attack
CEASIOM	= Computerized Environment for Aircraft Synthesis and Integrated Optimization Methods
CFD	= Computational Fluid Dynamics
L/D	= Lift-to-Drag Ratio
RDS^{win}	= Aircraft design software package *("Raymer's Design System")*
STOL	= Short Take Off and Landing
SUMO	= CFD model creation sketchpad software (SUface MOdeler)
T/W	= Thrust-to-weight ratio
UFO	= Unidentified Flying Object
W_o	= Aircraft Takeoff Gross Weight
W/S	= Wing loading (weight/area)

I. Introduction

Conceptual Research Corporation with the assistance of Airinnova AB of Sweden has recently performed a company-funded study of electric-powered personal aircraft inspired by the 1940's Vought V-173 "Flying Pancake." This odd design, often seen in books about unusual or terrible airplanes[1], was a demonstrator/prototype for the Navy's never-flown XF5U "Flying Flapjack" STOL fighter. Both designs have a low aspect ratio wing that is rounded in planform, with large propellers mounted forward of the wingtips such that the entire wing is within the propwash. This prevents stalling up to extreme angles of attack, and is also said to reduce drag-due-to-lift.

The new design concepts described herein were developed to help generate interest in the concept of "pocket airports." These are to be football-field-sized airports located within urban areas and intended for "green" electric-powered aircraft. Such fields will require extreme STOL performance and low-speed safety, bringing to mind the

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exceptional performance of the long-forgotten V-173. A preliminary, oral-only presentation of these “Sparky Flapjack” concepts was given at the 2016 Sustainable Aviation Symposium in San Francisco.

This paper begins with a brief review of the V-173 design concept. This is followed by four designs inspired by the V-173 ranging from a four-seat C-172 equivalent to a one-man recreational “mini” version. All use electric propulsion, novel aerodynamics, and integrated composite construction. Please note that the concepts below are notional design studies only, developed on a limited budget as a “what if” exercise. This author is not ready to say at this point if they will work as estimated or if they would be superior to conventional concepts.

Design and analysis work was done by Dr. Raymer using the RDS^{win}-Professional[2,3] aircraft design software from Conceptual Research Corporation. RDS^{win} is an integrated design environment which includes a design layout module for concept development, analysis modules for aerodynamics, weights, propulsion, stability, cost, performance, range, sizing, and optimization. The technical methods employed are largely those described in Raymer’s textbook *Aircraft Design: A Conceptual Approach*[4].

CFD work was done by Drs. Zhang and Rizzi of Airinnova AB using the CEASIOM analysis framework and the Swedish National CFD Solver program, based upon geometry modeled in SUMO from an RDS^{win} file by E. Raymer, summer intern at Airinnova.

II. Vought V-173 "Flying Flapjack"

In the 1930’s, NACA-Langley aerodynamic researcher Charles Zimmerman developed and patented a concept for a low aspect ratio, oval-planform aircraft with huge propellers at the wingtips as a way of providing for extreme low-speed flight (figure 1). With US Navy funding, Vought Aircraft was contracted to build and fly an initial demonstrator, to be followed by a prototype Naval fighter aircraft. The 2,260 lb. demonstrator, called the V-173 "Flying Pancake," was constructed of wood and canvas with two 80 hp piston engines driving 16.5 ft. three-bladed propellers. To obtain the required 22° angle of attack on the ground, a conventional landing gear arrangement (“taildragger) with ridiculously long main gear legs was used. This in turn required a transparent nose so that the pilot could see the runway in front of him, between his legs.

As a major benefit of this configuration, the huge propellers blow air across the entire wing so that wing stall is delayed until a high angle of attack is reached. A more-subtle feature of the design is that the propellers spin the “wrong way.” The outward blade is moving downward. Thus, the propeller swirl somewhat counteracts the tip vortex and allegedly reduces the drag-due-to-lift which would otherwise penalize such a low aspect ratio planform. In figure 2, an early version of the V-173 is being tested in the full-scale NACA wind tunnel.

The V-173 flew from 1942 to 1947, making 190 flights in all and generating numerous UFO reports. While often called the “Flying Pancake” it never received an official name. It flew well, could not be stalled or spun, and could take off or land in 50 feet – or zero feet with a slight headwind. Charles Lindbergh once flew it and spoke well of its handling qualities and low-speed abilities.

Problems included vibrations from the complicated gearboxes and power shafts, and gyroscopic stresses on the long propeller blades leading to helicopter-like articulated blades for the production version. Also, its low aspect ratio wing caused high deceleration in a tight turn.

This was followed by a prototype for a production USN fighter, the Vought XF5U "Flying Flapjack." It was only slightly larger yet seven times heavier (16,700 lbs gross, 13,100 lbs empty). Of all-metal construction, it had an ejection seat, four 20 mm cannons, and an external payload consisting of two 1,000 pound bombs. Wing area was 475 sqft with a span of 23 ft. Top speed was projected to be 413 knots, besting the Grumman F8F Bearcat with a top speed of 366 kts and the P-51 with top speed of 380 kts.

The XF5U-1 actually lifted off during taxi tests in 1947, but the Navy cancelled the program before the first actual flight would have taken place. By this time propeller fighters were obsolete - the jet P-80 which flew in 1944 could reach 521 kts – and there was no other use envisioned for such a design. The prototype was destroyed, on Navy orders. Humorously, the first steel wrecking ball dropped onto the wing just bounced off. Later attempts were more successful. Luckily, the original V-173 survives and is currently at the Frontiers of Flight Museum in Dallas, TX.

Since the days of the V-173 and XF5U-1, no aircraft of similar design has been built. However, the V-22 and other tilt rotor designs do employ "wrong way" propeller rotation, even though rotation with the outward blade moving downward tends to exacerbate engine-out controllability problems.

III. Sparky Flapjack V1 (4-Seater)

Dr. Brien Seeley of the Sustainable Aviation Foundation requested a design study of an electric-powered, V-173 derived aircraft to generate interest in the concept of "pocket airports[5]." These would be football-field-sized airports located within urban areas. The basic aircraft design requirements were simple – a runway length of 550 feet including obstacle clearance, quiet operation (~48db at a 40 meter sideline), and minimal pollution. The desired range is about 160 km (86 nmi) although more is better. Speed is of lesser importance although certainly it should be much faster than an automobile, even in the face of substantial headwinds.

For the first concept design, a four-seat capacity was chosen to make the design equivalent to the widely-produced Cessna 172. Looking at the V-173 configuration, an obvious problem was noted. How would normal people get into the cabin, if located high above the ground and at a 22° angle to horizontal?

To avoid this, a separate crew cabin was conceived which would be located underneath the "flapjack" wing. This allows normal entry unlike the V-173, where the pilot had to climb up and swing into the seat. The wing has a variable incidence angle so that the cabin doesn't have to rotate to the 22° that the wing needs for takeoff. Actuation would probably be via load-bearing tension cables, two ahead of and two behind the wing pivot point. Electric take-up reels would provide the pivoting action. The cabin has a small ventral tail to yaw-stabilize the underslung portion and to provide a streamlined mounting location for the tailwheel.

For initial layout purposes the 4-seater was sized to 3350 lbs. It uses two of the new Siemens 250kW electric aircraft motors. This is considered the latest state-of-the-art electric motor for aircraft. It puts out 261 kW (350 hp) and this is at 2500 rpm so that gearing is not required. It weighs 50 kg (110 lbs) and requires an inverter-controller which weights another 10 kg (22 lb.).

This design has 16 foot diameter props spinning at 900 rpm, and uses lithium-polymer batteries which are mounted in the wings. These are assumed to be in packs of 31 amp-hr each, weighing 33 kg (74 lb.) each.

The four-seat Sparky Flapjack V1 can be seen in figure 3. Key design parameters include:

- TOGW: 3,353 lbs
- Length: 25.5 ft
- Height: 9.0 ft
- Span: 22.5 ft
- Wing area: 385 ft²

Sparky Flapjack V1 Analysis

A conceptual-level analysis was done for the 4-seat V1 design using the classical routines of the RDS^{win}-Pro aircraft design software. Subsonic parasite drag was estimated by the component buildup method. Drag due to lift was calculated by the leading-edge suction method using a calculated Cl-alpha based upon DATCOM methods. Maximum lift was estimated using DATCOM charts.

When preparing inputs for the aerodynamic analysis, an adjustment had to be made to account for the expected benefit of the propwash rotational swirl. Prior computation studies by Piancastelli and colleagues[6] have shown that a benefit exists and can "improve the overall performance by improving the effective span length." For quick initial analysis, it was assumed that the average drag-due-to-lift benefit was equivalent to an increase in effective span equal to one-half the radius of the propeller. The aspect ratio used in the drag calculations were adjusted accordingly.

Aerodynamic results are summarized as lift-to-drag ratio in figure 4. As expected, the L/D is a bit low for a small general aviation design. This results from the low aspect ratio and fairly high wetted area of the "flapjack" wing compared to a normal design.

Propulsion analysis used standard propeller efficiency data to calculate propeller thrust and specific fuel consumption based upon engine power and RPM. Results were adjusted for tip Mach effects, blockage, and propwash.

Weights were estimated statistically for structure, propulsion, equipment, and useful load groups, using well-proven equations for general aviation aircraft. Adjustments were made for use of composite materials. To account for the pivoting wing mechanization and other items, 200 lbs was added to the empty weight.

The net available weight for batteries (960 lbs) was calculated as the remainder when empty weight and useful load are subtracted from takeoff gross weight. Results are tabulated below:

STRUCTURES GROUP	826.6	EQUIPMENT GROUP	80.6
Wing	214.3	Flight Controls	23.1
Horiz. Tail	48.5	Hydraulics	0
Vert. Tail	54.8	Electrical	32.5
Vert. Tail	6.4	Avionics	25
Nacelles	41.2		
Fuselage	277.9	Misc Empty Weight	200
Main Lndg Gear	150.4	We-Allowance 5.0%	75
Tail Lndg Gear	33.1	TOTAL WEIGHT EMPTY	1574.8
PROPULSION GROUP	392.6	USEFUL LOAD GROUP	1778.3
Engine(s)	220	Crew	180
Eng Installation & Props	172.6	Batteries	958.3
Fuel System	0	Oil	0
		Payload	100
		Passengers	540
		TAKEOFF GROSS WEIGHT	3353

The range and flight time of the Sparky Flapjack V1 was calculated by determining the required power settings from drag and thrust calculations at an assumed cruise speed (160 kts). The mission segment time was iterated until the total battery capacity required (kW-hr) equaled the battery capacity available, given the weight available for batteries. As shown below, this results in a range of 107 nmi range with 43 minutes of flight time.

Mission:	% max pwr	Time - min	Energy kW-hr	distance (nmi)	distance (mi)	V (kts)
TO & Climb	100	2	9.3			
Cruise	29.2	40	54.1	106.7	122.7	160
Loiter before landing	17.7	0.25	0.2	0.3	0.4	80
Landing	100	0.5	2.3			
	total	42.8	65.9			

IV. Sparky Flapjack V2 (2-Seater)

After reviewing the four-seater design, Dr. Seeley requested a smaller design concept with only two seats. Several studies have shown that most automobile trips and general aviation flights have only one or two people on board. Smaller size would also reduce cost, noise, and environmental impact. Thus, Sparky Flapjack V2 was developed, with wings and tails approximately 15% smaller than the V1 concept. The cabin is significantly reshaped to accommodate two people, side-by-side.

Two Duplex Emrax222 140kW electric motors were selected. These are 8" in diameter and 12” in length, weigh 25 kg (55 lbs), and put out 140 kw (187 bhp) for 5 minutes.

The V2 design concept can be seen in figure 5 and has design parameters as follows:

- TOGW: 2,057 lbs
- Length: 21.2 ft
- Height: 7.7 ft
- Span: 19.1 ft
- Wing area: 278 ft²

Sparky Flapjack V2 Analysis

A similar conceptual-level analysis was done for the 2-seat V2. Aerodynamic results (figure 6) are slightly better, probably because the fuselage pod is slightly smaller relative to the wing. Propulsion calculations were done using the same methods.

Weights were estimated similarly assuming typical composite general aviation structure. 150 lbs were added for the pivoting wing & miscellaneous items. This results in a net of 668 lbs available for batteries.

STRUCTURES GROUP	500.7	EQUIPMENT GROUP	74.6
Wing	131.8	Flight Controls	17.2
Horiz. Tail	29.6	Hydraulics	0
Vert. Tail	34.3	Electrical	32.5
Vert. Tail	3.2	Avionics	25
Fuselage	19.7		
Fuselage	144.4	Misc Empty Weight	150
Main Lndg Gear	112.8	We-Allowance 5.0%	46.6
Nose Lndg Gear	24.8	TOTAL WEIGHT EMPTY	979.1
PROPULSION GROUP	207.2	USEFUL LOAD GROUP	1077.9
Engine(s)	110	Crew	180
Eng Installation & Props	97.2	Batteries	667.9
Fuel System	0	Oil	0
		Payload	50
		Passengers	180
		TAKEOFF GROSS WEIGHT	2057

Sparky Flapjack V2 was analyzed for cruise speeds of 160 kts and 200 kts, with results below. At 160 kts the aircraft obtains 168 nmi range with 58 minutes of flight time. Speeding up to 200 kts reduces range to 115 nmi with 33 minutes of flight time.

Mission:	% max pwr	Time - min	Energy kW-hr	distance (nmi)	distance (mi)	V (kts)
TO & Climb	100	2	5.2			
Cruise	55.8	30	43.4	100.0	115.1	200
Loiter before landing	16.5	0.25	0.1	0.3	0.4	80
Landing	100	0.5	1.3			
	total	32.8	50.0			

Mission:	% max pwr	Time - min	Energy kW-hr	distance (nmi)	distance (mi)	V (kts)
TO & Climb	100	2	5.2			
Cruise	30.8	55	43.9	146.7	168.8	160
Loiter before landing	16.5	0.25	0.1	0.3	0.4	80
Landing	100	0.5	1.3			
	total	57.8	50.5			

The table below tabulates results for Sparky Flapjack concepts V1 and V2. It also compares them with the Flying Flapjack prototypes and with two typical general aviation aircraft, the old but still productive Cessna 172, and the modern Cirrus SR22.

	V-173	XF5U	C-172	Cirrus SR22	Sparky Flapjack	Sparky Flapjack2
Wo	2258	16722	2450	3600	3353	2057
Wing Area S	427	475	174	145	381	278
span	23.25	32.5	33	33	22.5	19.1
Hp (each)	80	1350	160	310	335	187
#motors	2	2	1	1	2	2
Wo/hp	14.1	6.2	15.3	11.6	5	5.5
W/S	5.3	35.2	14.1	24.8	8.8	7.4
Stall speed kts	30.4	20.0	47	60	30	30
Max speed kts	119.9	546.6			245	235.0
Stall speed mph	35.0	17.4	54	69	34.5	34.5
Max speed mph	138.0	475.0			281.9	270.4
ROC fpm	714	3000	721	1270	4900	4100
q - stall	3.14	1.36	7.49	12.20	2.88	3.05
Clmax est.	1.69	25.93	1.88	2.03	2.88	2.43

V. Sparky Flapjack V3 (2-Seater)

After completing these two baseline concepts, several side studies were done. First, the thought occurred to attempt a design that is almost directly derived from Charles H. Zimmerman's work. In other words, get rid of the separate podded cabin and go back to the original idea of a cabin integrated with the wing root, high off the ground.

This design, a two-seater based on the V2 concept above, is shown in figure 7. Note that the cockpit sits at a crazy angle, requiring the people to climb up the back of the wing and somehow swing into the seats, feet higher than head. However, the reduction in weight and drag associated with the separate body pod of V2 would substantially increase range.

Time did not permit a full analysis, but the empty weight should reduce by roughly 120 lbs and L/D should increase by about 10%, yielding a range increase of about 30%.

However, the awkward and potentially dangerous entry and egress would make this concept a loser as a manned aircraft. Perhaps it makes sense as a UAV.

VI. Sparky Flapjack V4 Mini

The final Sparky Flapjack concept is a bit wild. The main problem with V3 is the entry and egress. This could be fixed by returning to Zimmerman's original patent concept, and with a prone pilot position. Entry would be even easier if there were no top door to open and shut.

A one-person Sparky Flapjack "mini" with this in mind is shown in figure 8. This is conceived as a recreational toy, similar to a motorcycle where the rider is exposed to the elements. For boarding the pilot steps up and flops forward to a prone position on top of the wing. The pilot would put on a parachute first, and would clip its harness to the aircraft once in place. These would have quick disconnects so that the pilot could easily bail out in flight.

A range of about 150 nmi range at a speed of about 120 kts is expected. Takeoff distance should be well under 50 feet, allowing flight from almost anywhere.

VII. Sparky Flapjack CFD

Swedish aerodynamic research firm Airinnova AB performed a preliminary CFD Euler analysis using the SUMO modeling tool linked to the CEASIOM analysis framework and the Swedish National CFD Solver program. This flow solver, developed originally at the Swedish Defense Research Agency (FOI) by Eliasson[7] and later in collaboration with SAAB aircraft[8] and Swedish university researcher partners[9], uses an edge-based formulation on unstructured node-centered finite-volume grids, as defined by geometry modeler SUMO.

A simplified version of the Sparky Flapjack V4 Mini was created, with cockpit cavity and exposed pilot removed to avoid computational difficulties. This was exported from RDS^{win}, modeled in SUMO (figure 9) and then turned into a surface mesh which was used to make an unstructured volume mesh CFD grid[10] of about 5 million cells (figure 10).

The propeller disk was modeled using actuator disk theory based on required thrust calculated from the classical drag analysis done in RDS^{win}. Uniformity and incompressibility were assumed, and viscous effects were neglected. The airflow effect of the propeller was implemented by using the mass flow boundary conditions to define the required mass flow rate. This allows the total pressure to vary in response to the interior solution. Analysis was done at 160 kts (Mach .242) and low altitude (2km), using a four-core 3.7GHz HP workstation. Each case took about 30 minutes.

Resulting lift, drag, and pitching moments are shown in figure 11. Clearly the large propellers are aiding the wing in generating lift and delaying stall. Unsteady effects prevented continuing to even higher angles of attack, but since the ground line on landing is limited to 22 degrees, greater angles are unusable.

Lift and drag are strongly affected by the propeller flowfield. At 15 deg AOA, the prop-on case gets 29% more lift. L/D is about 3% worse. At the 20 degree AOA needed to get the same lift without propeller effects, the prop-off L/D is much worse. Prop-on L/D is 43% better than prop-off getting the same total lift.

Flowfield effects can be seen in figure 12, at 15 degrees AOA. Red lines indicate power-off and the lower black lines indicate power-on. Results would appear more dramatic if a full unsteady, viscous analysis was conducted, but it can be observed that the propeller strongly affects the flowfield over the whole vehicle.

Note that for this preliminary CFD, the propeller swirl was not modeled. Thus, the potential drag-due-to-lift benefit of the “wrong way” propeller rotation could not be assessed.

VIII. Summary & Conclusions

Four electric-powered personal aircraft were designed based on the WWII-era Vought V-173 "Flying Pancake," which featured a rounded low aspect ratio wing and large propellers mounted forward of the wingtips. This delays stalling and provides high lift at extreme angles of attack, and could reduce drag-due-to-lift under certain flight conditions. The basic mission requirement for these designs was to operate within the confines of a so-called “pocket airports,” short field airports to be located within urban areas.

All four concepts look broadly feasible. Preliminary calculations indicate reasonable range, endurance, and speed. Detailed design layout and analysis is required to validate these preliminary numbers and determine if the concepts might prove feasible and superior to other approaches for a STOL personal aircraft. CFD results show a strong effect of the propeller on the total vehicle flowfield, and the L/D is greatly improved for the same lift.

Figures:

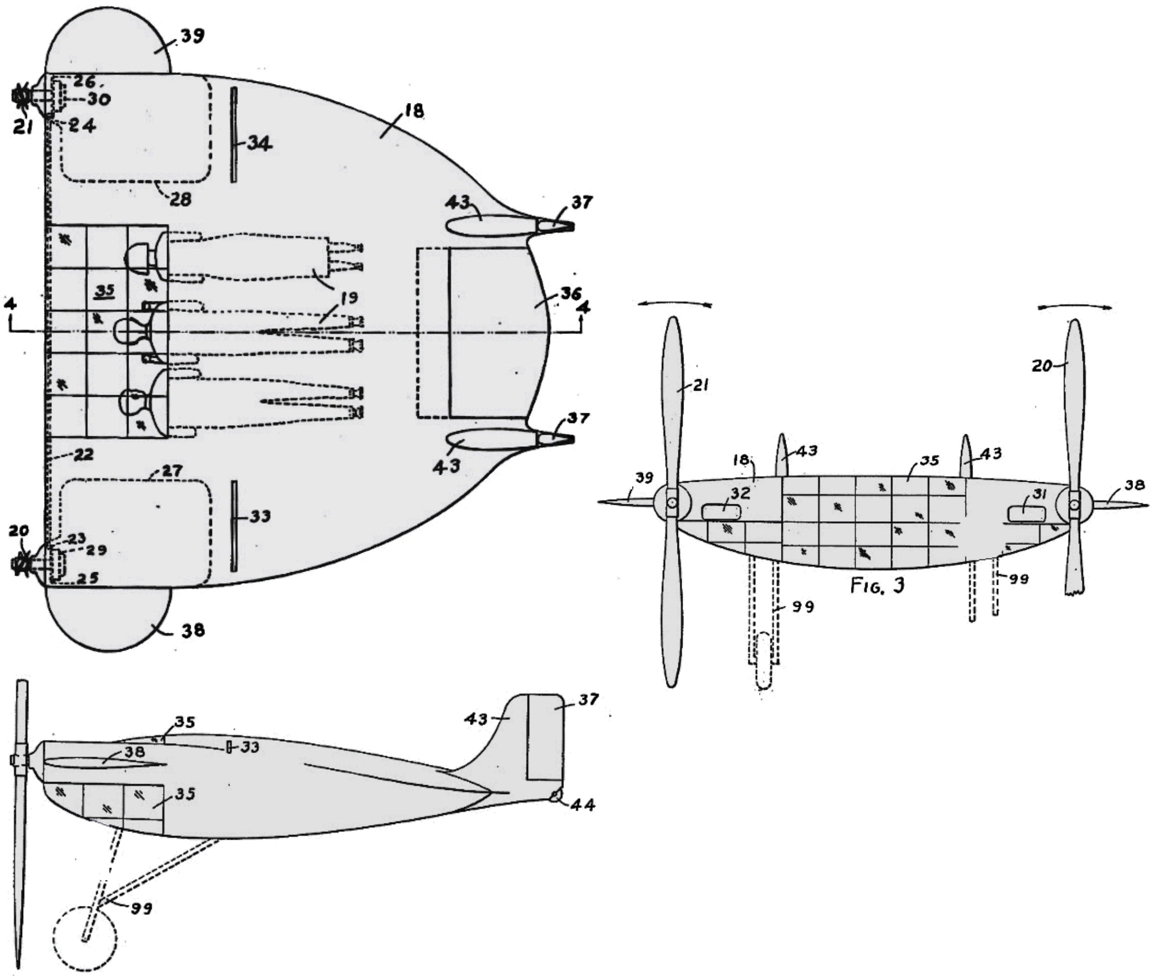

figure 1. Original Patent Drawing (1935)

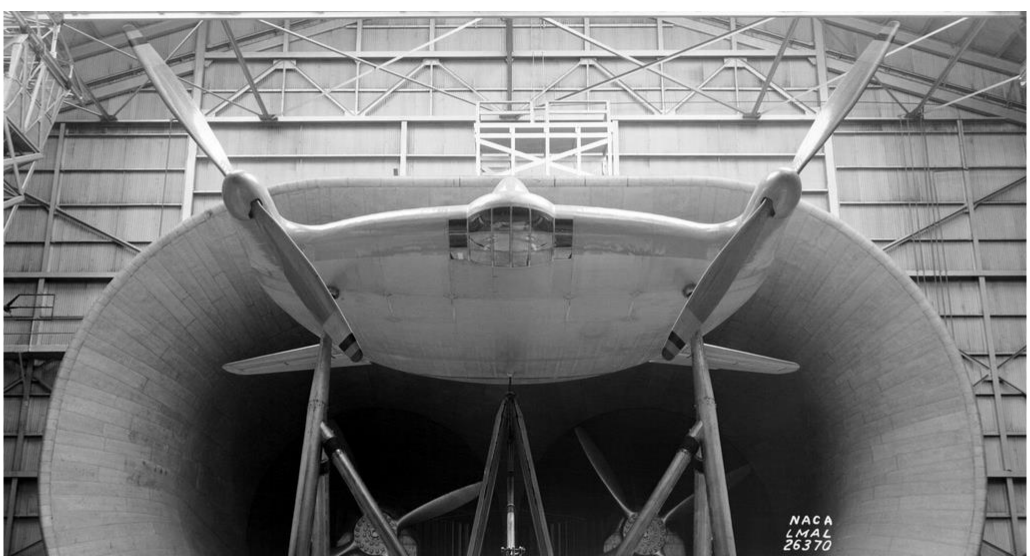

figure 2. V-173 in NACA-Langley 30x60 Full Scale Wind Tunnel (NACA photo)

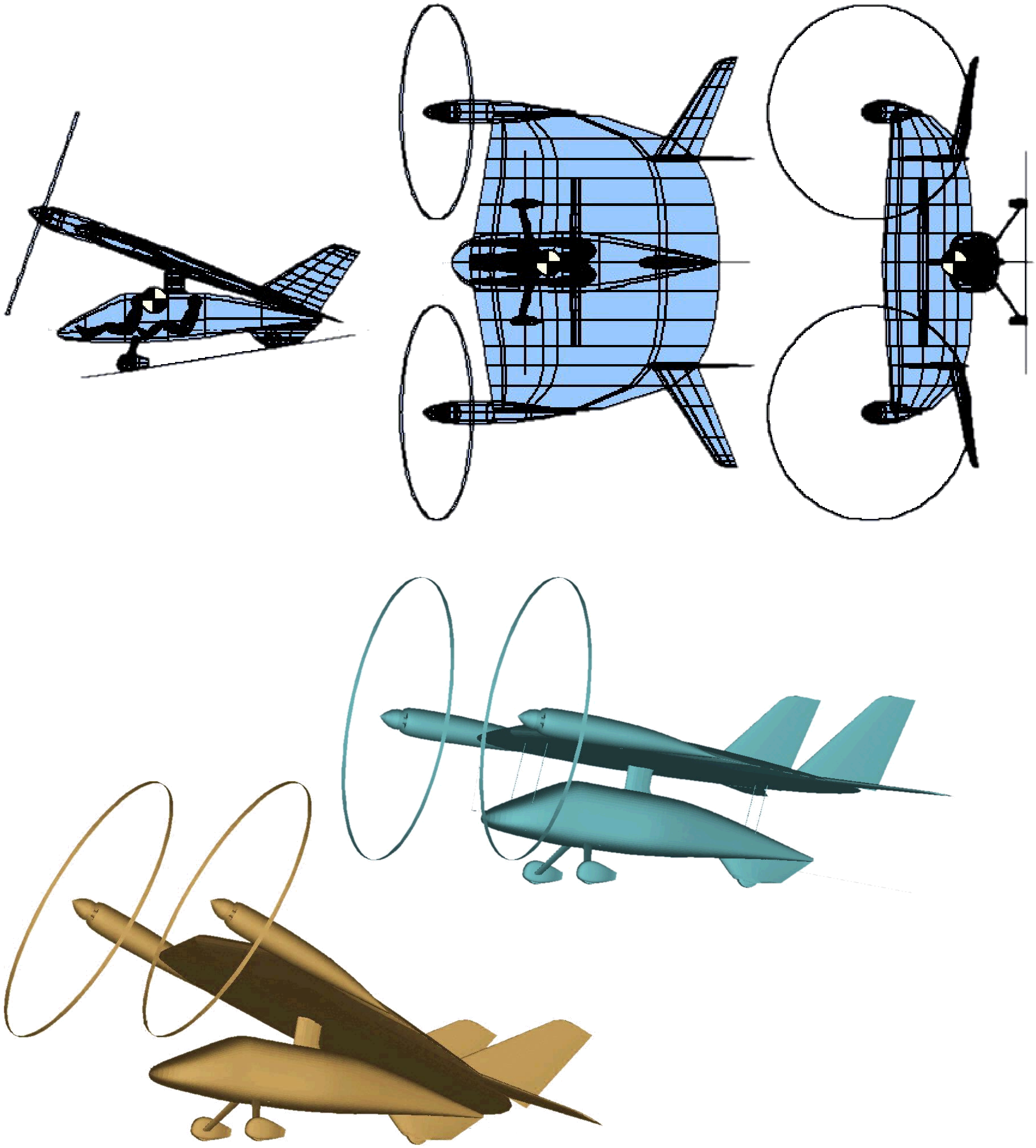

figure 3. *Sparky Flapjack 4-seater*

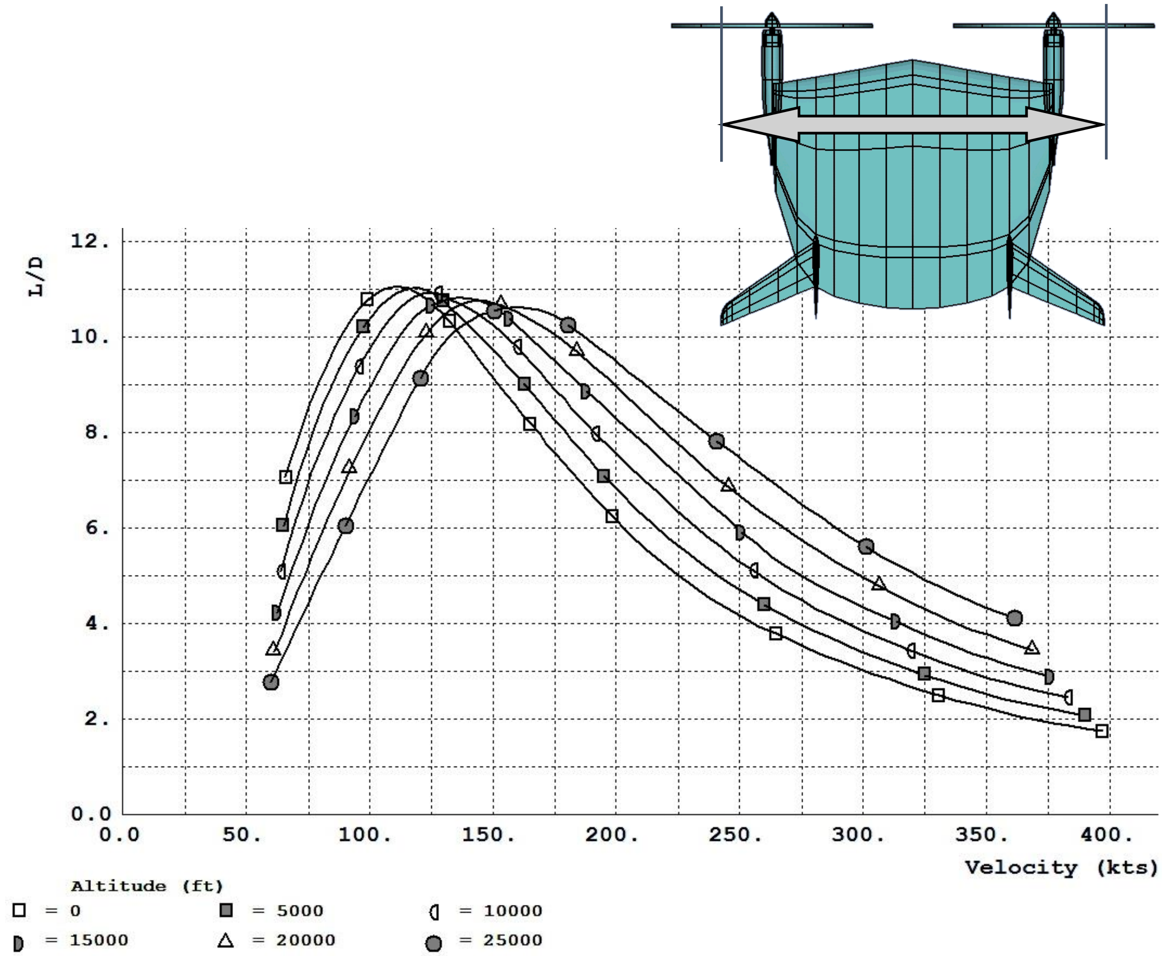

figure 4. Sparky Flapjack V1 Lift to Drag Ratio

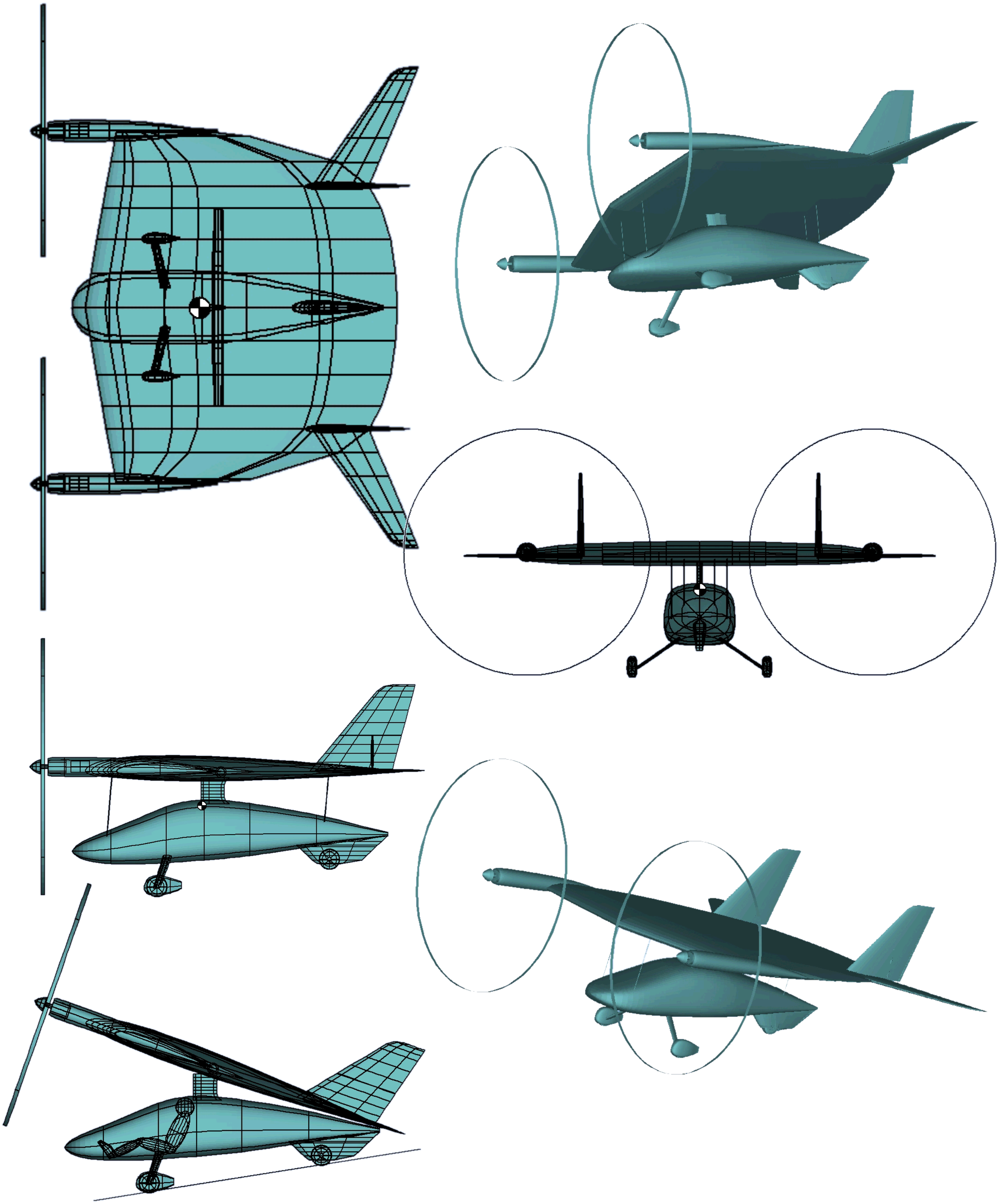

figure 5. Sparky Flapjack V2 2-seater

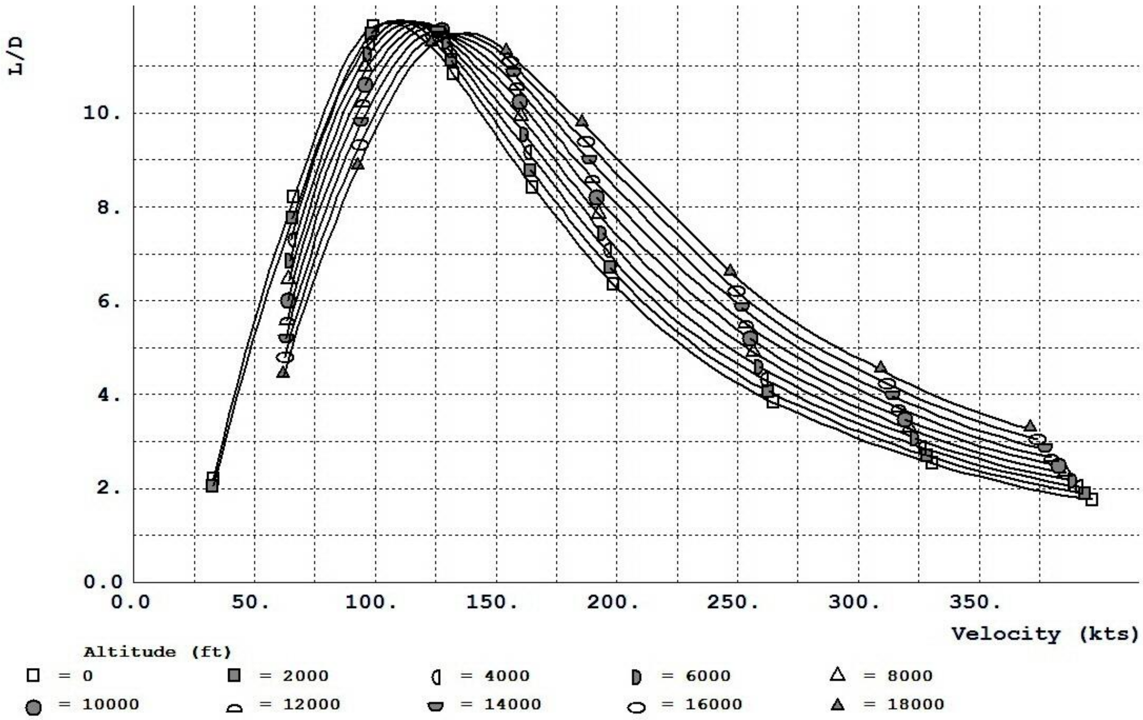

figure 6. *Sparky Flapjack V2 Lift to Drag Ratio*

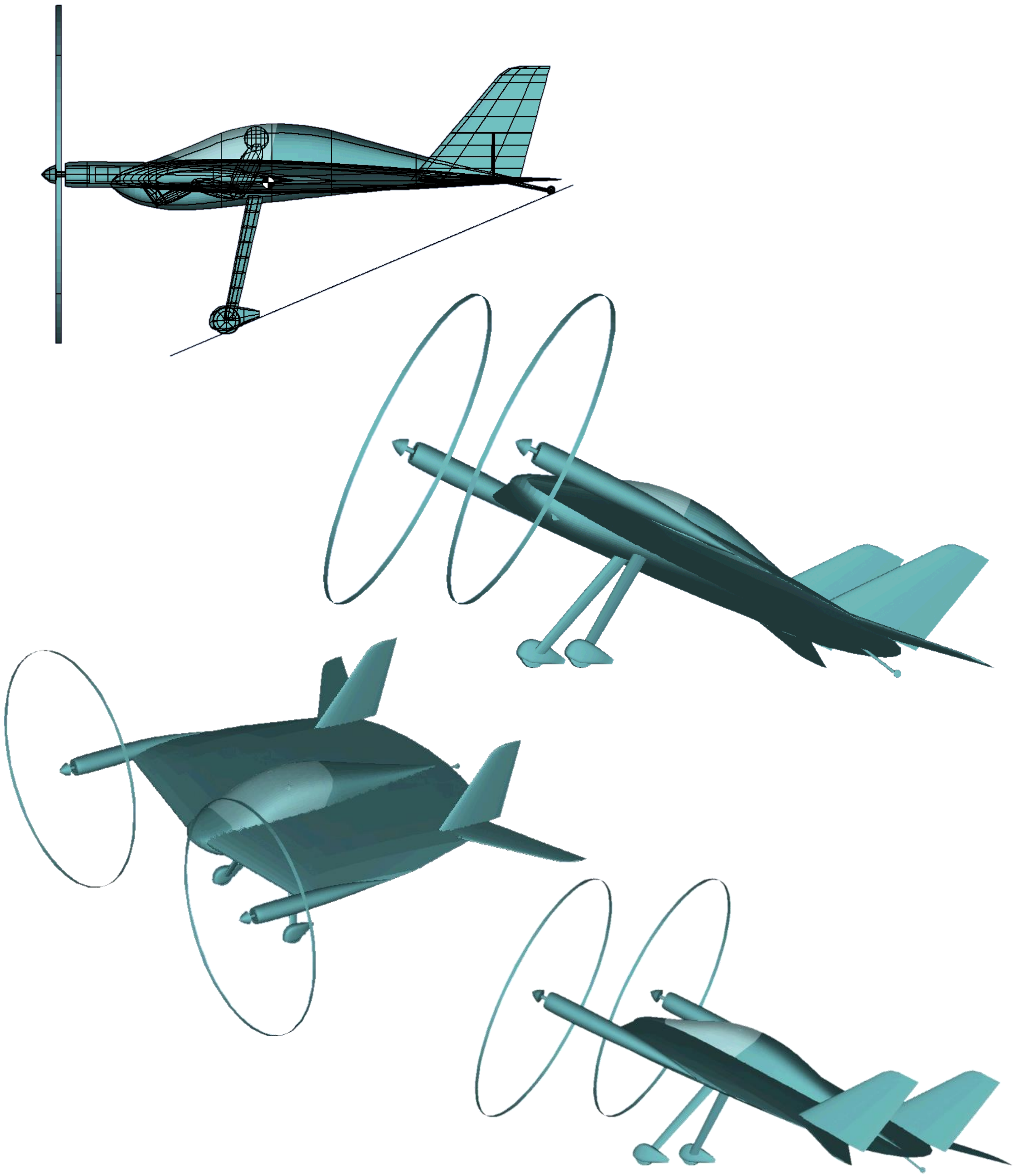

figure 7.　　Sparky Flapjack 2-seater (high cabin)

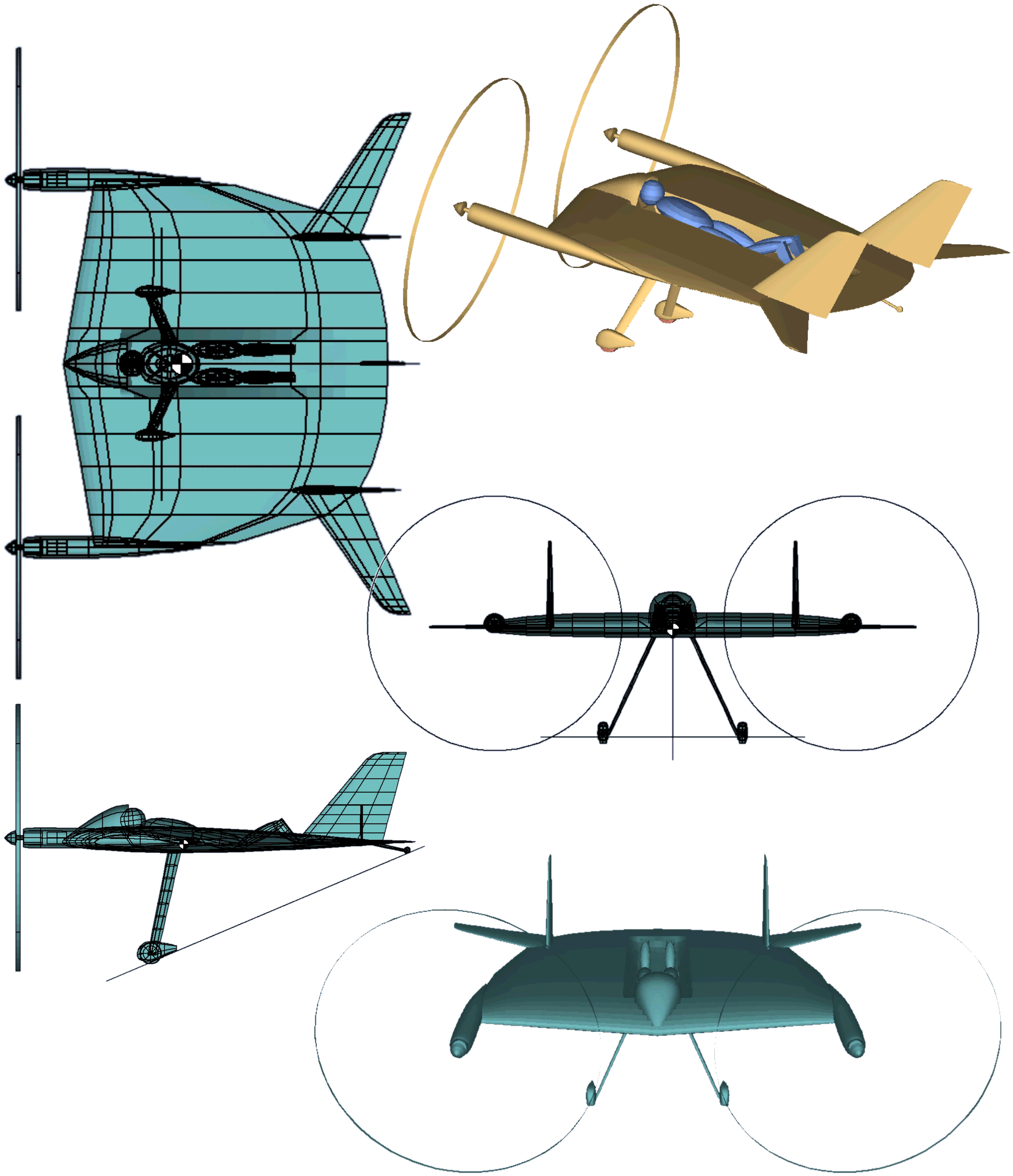

figure 8. Sparky Flapjack Mini (open single seater)

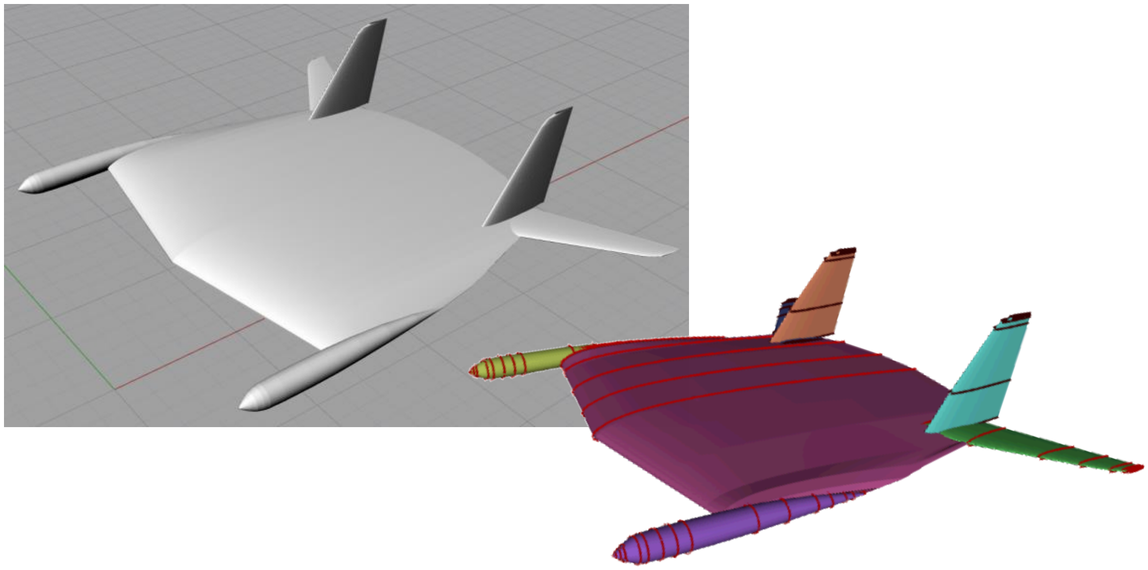

figure 9. *Simplified CAD and Initial SUMO Models*

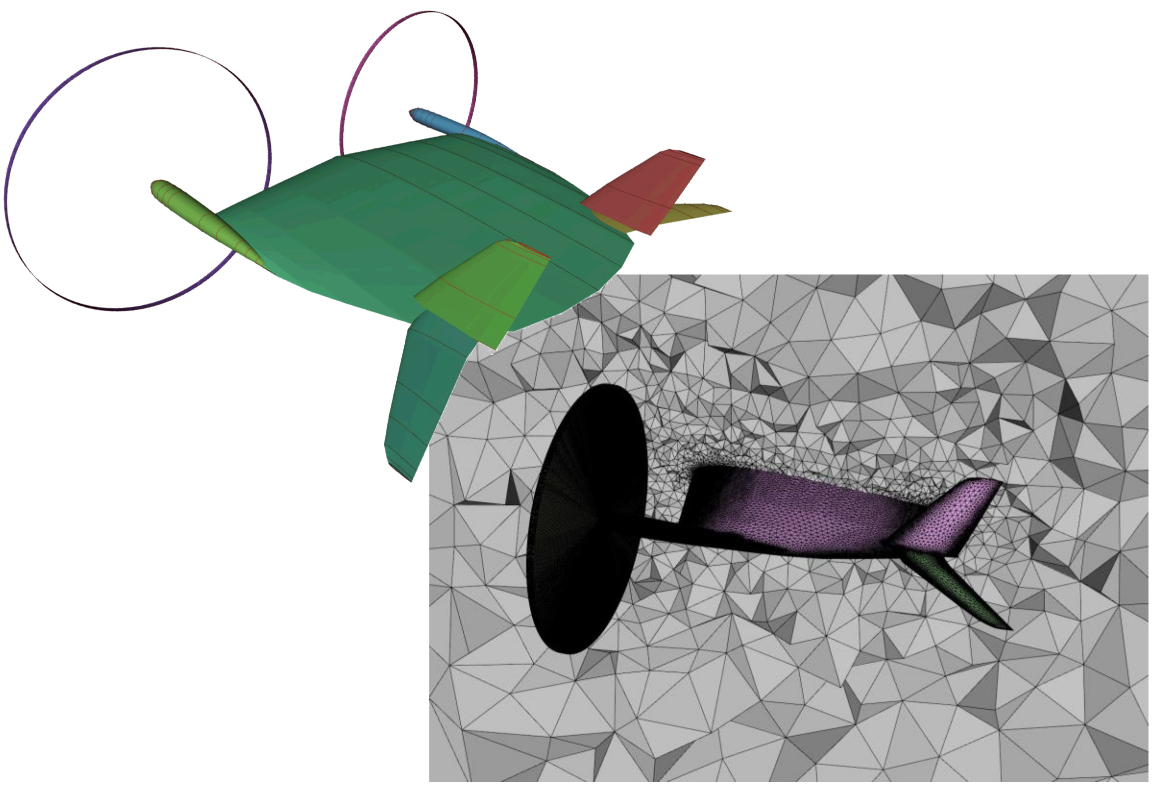

figure 10. *Final SUMO Model and CFD Unstructured Grid*

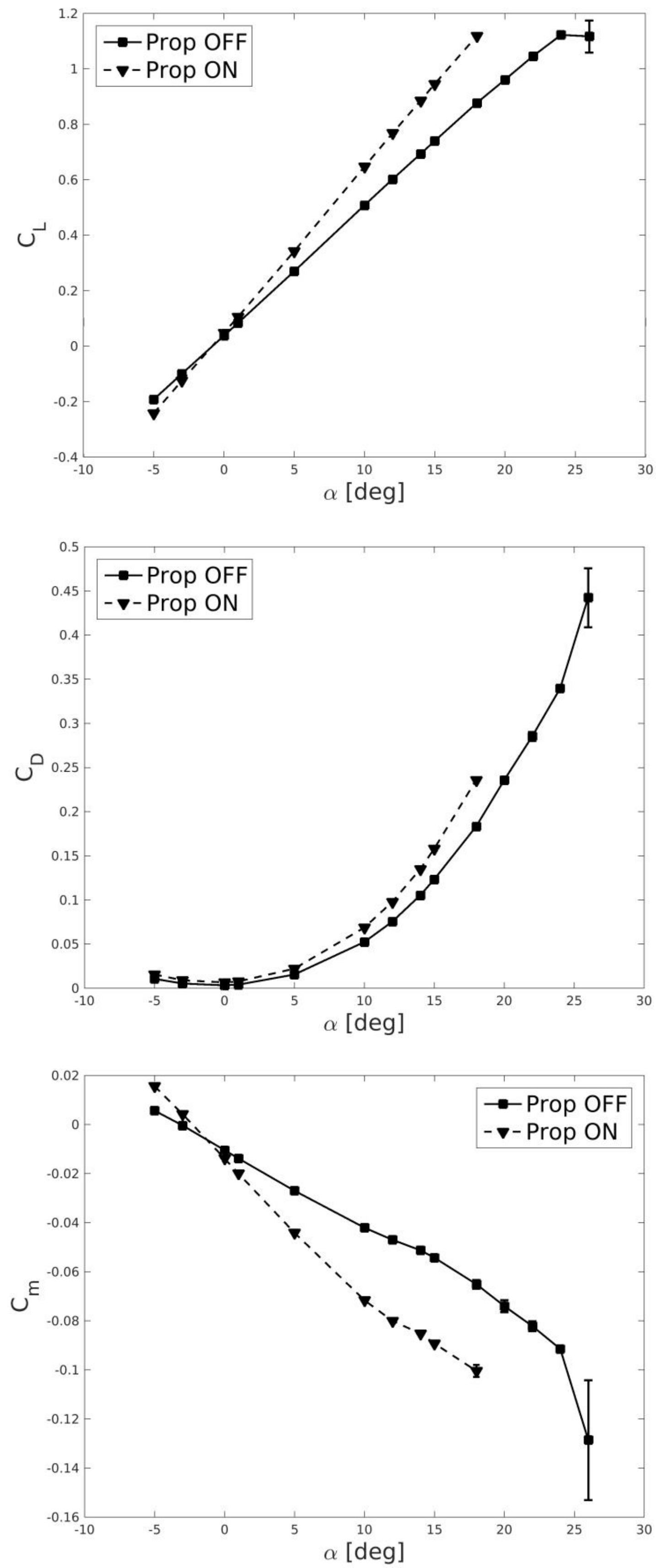

figure 11. Lift, Drag, and Pitching Moment Comparisons

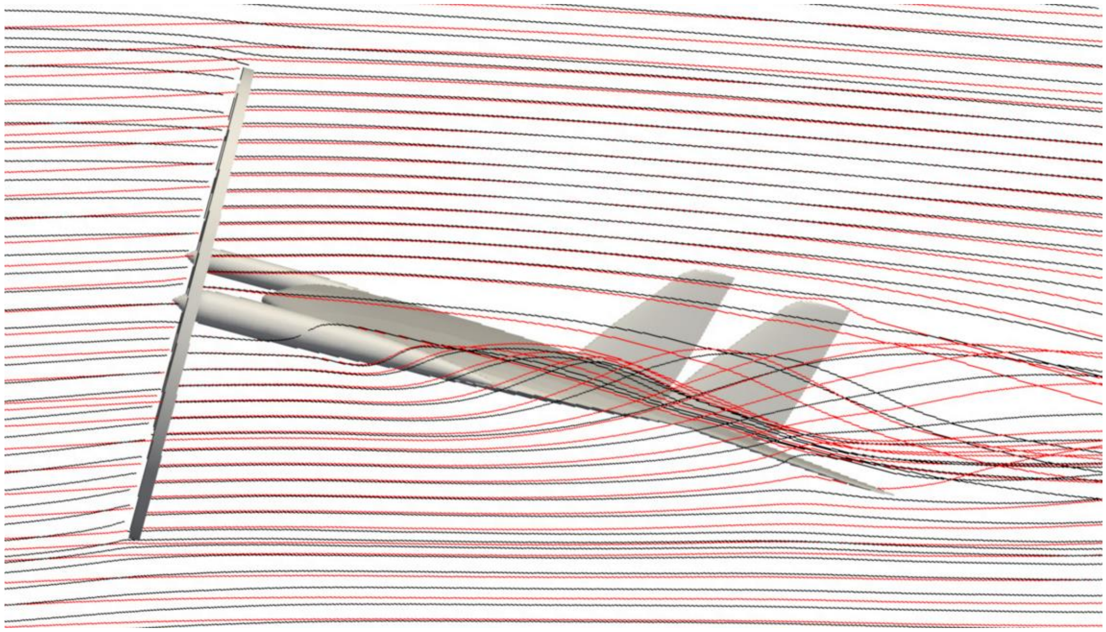

figure 12. CFD Flow Visualization (power-on vs. power-off)

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