Undergraduate Contribution to Dynamically Scaled General Aviation Research at the University of Illinois at Urbana-Champaign

Mohammed Qadri,[*] Moiz Vahora,[†] Rodra W. Hascaryo,[‡] Sean Finlon,[§]
Or D. Dantsker,[¶] Gavin K. Ananda,[‖] and Michael S. Selig[**]

Department of Aerospace Engineering, University of Illinois at Urbana–Champaign, Urbana, IL 61801, USA

General Aviation Upset and Stall Aircraft Recovery (GA-USTAR) is a project being conducted by the Applied Aerodynamics Group at the University of Illinois at Urbana-Champaign. GA-USTAR aims to construct a 1/5th dynamically-scaled Cessna 182 model to validate upset and stall flight simulations for general aviation aircraft. Dynamic scaling is the process by which a scale model of an aircraft can be modified to match the flight characteristics of the full-scale through scaling of mass and other properties. This paper details the contributions of undergraduate research assistants in the development of the GA-USTAR project and the subsequent educational value of undergraduate research. The undergraduate contributions discussed in this paper include the building of a stock Top Flite Cessna 182 Skylane model for baseline testing, determination of modifications necessary to dynamically scale the model to match the mass properties of the full-scale, creation of a weighted CAD model of the scale model, as well as initial flight testing. Through participation, the undergraduate research assistants gained valuable skills, experience, and insight applicable in both academia and industry that they would not have otherwise obtained through the undergraduate curriculum.

Nomenclature

AR	=	aspect ratio
AGL	=	above ground level
ARF	=	Almost-Ready-to-Fly
CAD	=	computer-aided design
CG	=	center of gravity
ESC	=	electronic speed controller
GA	=	general aviation
R/C	=	radio control
$TOGW$	=	takeoff gross weight
b	=	wingspan
CG_x, CG_y, CG_z	=	longitudinal, lateral, and vertical center of gravity
I	=	moment of inertia
I_{xx}, I_{yy}, I_{zz}	=	roll, pitch, and yaw moment of inertia
L	=	length of fuselage
n	=	model to full-scale ratio
S	=	wing area
$TOGW_{min}$	=	takeoff gross weight minus fuel

[*]Undergraduate Student, AIAA Student Member. mqadri4@illinois.edu
[†]Undergraduate Student, AIAA Student Member. mvahor2@illinois.edu
[‡]Undergraduate Student, AIAA Student Member. hascary2@illinois.edu
[§]Undergraduate Student. sfinlon2@illinois.edu
[¶]Graduate Student (Ph.D. Candidate), AIAA Student Member. dantske1@illinois.edu
[‖]Graduate Student (Ph.D. Candidate), AIAA Student Member. anandak1@illinois.edu
[**]Professor, AIAA Associate Fellow. m-selig@illinois.edu

UAV	=	unmanned aerial vehicle
W	=	weight
W/S	=	wing loading
σ	=	atmospheric density ratio
ν	=	kinematic viscosity
ν_o	=	kinematic viscosity at sea level

I. Introduction

Since the development of the Wright Flyer, scale aircraft models have been used to design and test new aircraft configurations.[1] These scale models were often used to simulate aircraft dynamics and aerodynamics in a manner more safe and cost effective than full-scale tests. Wolowicz et al.[2] discussed how simply scaling an aircraft and testing it are not enough to accurately simulate aircraft motions, as dynamics and aerodynamics change with weight and Reynolds number, requiring the models to employ correction factors before any data can be obtained. Two of the most common methods of testing scale models are static models tested inside wind tunnels and free-flying models. Experiments with stationary models are useful for modeling aerodynamics and are easier to control than free-flying models, but one limitation is their inability to model aircraft dynamics; free-flying models, however, are capable of modeling the motions and aerodynamics of aircraft. Using these models, modern commercial and military aircraft have been improved by allowing researchers to understand flight behaviors and improve their safety protocols.[1]

A dynamically scaled model is a free-flying scaled aircraft model that is capable of simulating the motions of a full-scale aircraft. "Dynamic scaling" of a model is accomplished by scaling the mass of the corresponding full scale aircraft through the square-cube law, which states that scaling an object linearly results in cubic scaling of its mass and squared scaling of areas. In addition to mass scaling, dynamic scaling requires matching mass distributions by scaling the moments of inertia of the modeled aircraft. The advantage of a dynamically scaled model over a stationary model or full-scale aircraft is its ability to test a wide range of aircraft maneuvers safely and cost effectively.[1]

The General Aviation Upset and Stall Aircraft Recovery (GA-USTAR) project aims to create a 1/5th dynamically scaled model of the Cessna 182 by modifying a Top Flite 1/5th-scale Cessna 182 R/C model.[3,4] The model is intended for experimental validation of a simulation that models the Cessna 182 in upset and stall states. Although extensive research exists for the behavior of commercial and military aircraft in such states, very little information is available for General Aviation (GA) aircraft such as the Cessna 182. Detailed in this paper are the contributions to the project made by undergraduate research assistants. This project was also meant to be of educational value to the undergraduate assistants who partook in it. The skills and experiences they gained through contributing to the project complements their undergraduate curriculum by giving the students an opportunity to apply what they learned into a research setting. These skills also serve as a way to diversify the skill sets of the students involved in the project, as they were taught how to conduct research in an independent manner, communicate with each other and the graduate mentors to move the project forward, as well as how to conduct research safely and effectively. The contributions discussed here include the building of a stock Top Flite model, generation of a weighted CAD model of the aircraft, determination of modifications necessary to dynamically scale the stock model, and baseline flight testing.

II. Cessna Build Process

As part of a larger dynamic scaling project, an R/C scale general aviation aircraft model was built for baseline flight testing and future dynamic scaling modifications. Students were exposed to several techniques that are used in building RC aircraft, ranging from laser-cutting to milling. Much was learned about the building of small scale aircraft including the components used to operate the model and the instrumentation used to evaluate the performance of said aircraft. The knowledge and subsequent flight test data resulting from this build process will help extensively in the dynamic scaling project in which this build is essential for developing a baseline configuration. The building of this aircraft was of particular importance to the undergraduate research assistants as a standard aerospace undergraduate curriculum does not require classes that aid in the development of such practical skills.

The stock model aircraft that was selected to be built and later dynamically scaled was the Top Flite Cessna 182 Skylane Almost-Ready-to-Fly (ARF) kit (Model TOPA0906).[5] It is a nominally 1/5-th scale model of the full-scale Cessna 182 Skylane. Characteristics of the stock model are tabulated in Table 1. As the model was Almost-Ready-to-Fly (ARF), some components of the model had already been completed by the manufacturer. The main wing and horizontal stabilizer were separate from their respective control surfaces and detached from the fuselage in separate pieces. Each wing and stabilizer piece, however, had its internal ribs already covered in Monokote. Fuselage bulkheads and formers had been joined with longerons and covered with Monokote as well. The wing tips, landing gear, landing gear wheels, landing gear pants, cowl, tail cone, rudder, spinner, elevators, windshield, and windows were fabricated as separate pieces but still required assembly. An image detailing the components in the ARF kit can be seen in Fig. 1.

To improve the utility of the model as an unmanned aerial vehicle (UAV) for flight testing, there were some modifications and deviations from the build manual. These changes affected many aspects of the build, ranging from modifications to the elevator control surfaces to the integration of sensors and instrumentation. The following sections will detail the entire build process of the model from start to finish, including the modifications to the standard build process of the model. This build was particularly important in the development of skills and experience for the undergraduate research assistants. Whereas an undergraduate curriculum is fairly thorough in developing concepts in the field of aerospace, not much is required in the way of practical application. With the burgeoning market for UAV's , hands-on skills and experience with the manufacturing, operation and integration of small-scale aircraft may prove invaluable to students looking to enter the industry.

Table 1. Characteristics of 1/5th Scale Cessna 182[5]

Geometric Properties	
Wingspan (b)	81.0 in (2060 mm)
Wing Area (S)	898 in^2 (57.9 dm^2)
Aspect Ratio (AR)	7.47
Overall Length (L)	64.0 in (1630 mm)
Inertial Properties	
Weight (W)	11.5 – 12.5 lb (5.22 – 5.44 kg)
Wing Loading (W/S)	30 – 32 oz/ft^2 (92 – 98 gr/dm^2)

Figure 1. Components of Top Flite ARF kit [taken from Top Flite].[5]

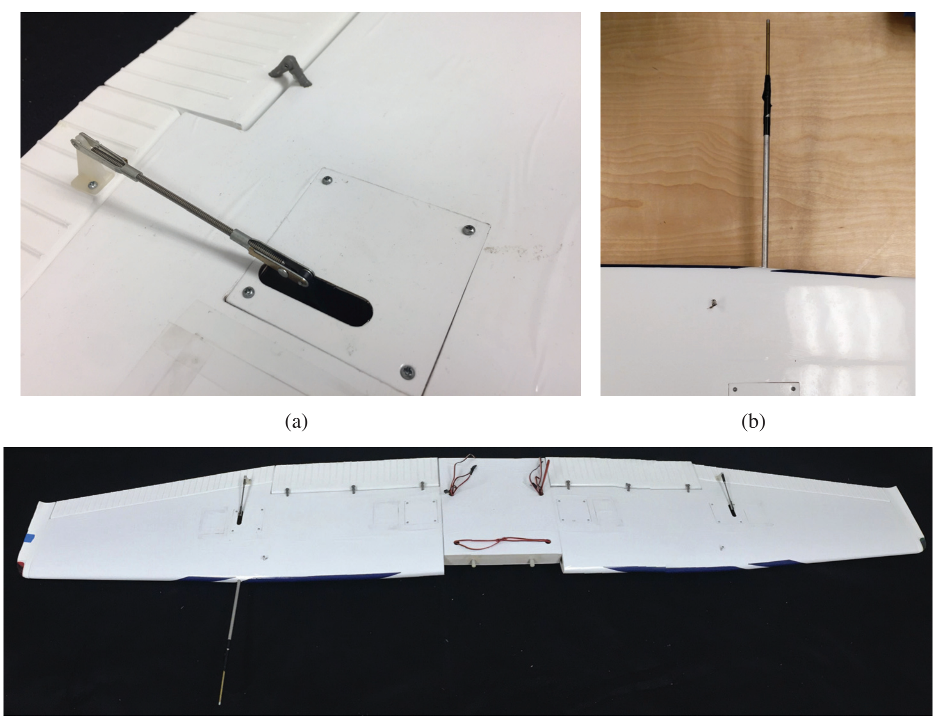
A. Main Wing

The wing for the ARF model came in nine separate major parts, including three wing sections (left, center, right), two ailerons, two flaps, and two wing tips. The first step in building the wing was to join the three separate wing sections. Provided wood and metal joiners were assembled and coated with epoxy, after which they were used to secure the three main wing sections to each other by insertion into pre-made slots in the end ribs. Special care was needed during the assembly and insertion of the joiners as an error could result in uneven dihedral for the wing. Wing tips were attached after the three main sections of the wing were assembled, using guide-strings to run wires through the wing ribs to holes open to the cabin of the model.

Following the joining of the major wing sections, the control surfaces (ailerons and flaps) were attached to the wing at predefined locations along the trailing edge of the joined main wing sections. These control surfaces were attached to the wing through a series of plastic and CA hinges. A few drops of thin CA were applied to the CA hinges, which were then placed in thin slits on both the wing trailing edge and the leading edges of the control surfaces. Thirty-minute epoxy was applied to the ends of the plastic hinges, which were then inserted into corresponding holes in the wing and control surfaces and then left to cure and harden. This was done repeatedly until both ailerons and flaps were secured to the wing and the joints were examined to ensure a full range of motion.

Once the hinges were in place, the process of installing servos in the wings was begun. Four Futaba S3010 standard high-torque ball bearing servos were screwed into wooden mounting blocks glued to the inside of the servo hatch covers in the wings. The same model of Futaba servos were used more extensively in subsequent parts of the build and will be discussed in more detail in Section E. Guide-strings were used to run servo wires to the holes in the center section of the wing for access to other electronic components that would be housed in the aircraft cabin. With the servos mounted to the hatch covers, control horns and pushrods were screwed to the control surfaces and servo arms to provide control.

The final step of the standard build for the wing was the installation of two nylon wing dowels at the leading edge of the center wing section that would fit into a former at the top of the cabin. Two nylon bolts would be used to attach the wing to the fuselage. It was at this point that a deviation was made from the prescribed build process in the manual. A pitot probe was added to the left wing section for data acquisition during flight testing of the completed model. Images of the control surfaces horns, pitot probe, and completed wing can be seen in Fig. 2.



(a) (b)

(c)

Figure 2. Wing build: (a) control horn and plastic hinges used to attach and control ailerons and flaps, (b) pitot probe inserted in right wing, and (c) completed wing.

B. Tail

Following the completion of the wing, work began on building the tail and related components. A dry fitting of the horizontal stabilizer was performed to ensure that it would be properly aligned with and parallel to the main wing. Epoxy was applied to the central portion of the horizontal stabilizer, which was then inserted into a slot in the tail perpendicular to the vertical stabilizer. The ARF kit came with a single metal elevator joiner rod; instead of using this provided single rod, a pair of custom made elevator joiner rods were used. This change was made because using a single elevator joiner rod, as suggested by the manufacturer, has a few key disadvantages. Firstly, use of a single joiner rod for both elevators means that there is no independent control authority for both surfaces. Additionally, the provided single joiner rod is asymmetrical, with its main shaft being off-center within the tail. As a result, moving the joiner rod has an asymmetrical effect and yields differential elevator deflection. Conversely, use of independent joiner rods for both elevators allows of independent control authority for both elevators, which is advantageous for flight testing. It also results in servo redundancy and ease of tuning.

Once the tail was inserted, it was checked for alignment and then elevators were installed on each side of the horizontal stabilizer in a process like that used for the main wing control surfaces. Unlike the process for those control surfaces, only CA hinges were used to secure the elevators; whereas, the wing control surfaces used CA and plastic hinges. After the elevators were securely attached, epoxy was poured down a hole at the base of the vertical stabilizer. A rudder steering rod encased in plastic tubing was inserted through the same hole at the trailing edge of the vertical stabilizer. As was the case with the elevators, CA hinges were used to install the rudder onto the vertical stabilizer after it had been slotted onto the rudder steering rod. This rudder steering rod led to some complications in the build, however. Both the steering rod and the slot into which it was inserted in the rudder were imprecisely manufactured, resulting in a rather loose rudder for the aircraft. When any appreciable amount of force was applied to the surface of the rudder, it would deflect without there being a corresponding deflection in the steering rod. This may translate to inaccurate data acquisition as the information obtained from the servo controlling the steering rod may not actually conform to the behavior of the rudder during flight. This is an aspect of the build that may be improved upon in future work.

Following this was the installation of the tail cone to house the internal components and streamline the empennage. First, a small notch was made in the pre-fabricated tail cone to allow for movement of the rudder steering rod. The tail cone was then slotted into the fuselage at pre-made holes, after which locations of fuselage internal wood bulkheads were determined. Holes were hand-drilled through the tail cone and bulkheads while screws were inserted to hold the tail cone in place. Once this had been done, wiring was installed for the internal components. Additionally, several wood pieces needed to be laser-cut to properly secure and align control arms connecting the tail control surfaces to their respective servos. Fig. 3 shows the pair of elevator control horns that were produced, the rudder steering rod and its plastic tubing, as well as screw attachment locations for the tail cone.

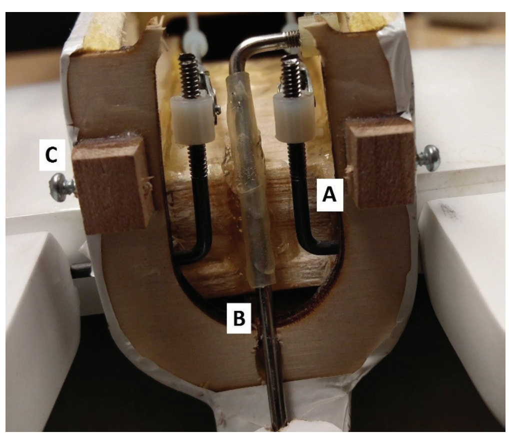


Figure 3. Tail components: (A) elevator control horns, (B) rudder steering rod, and (C) tail cone screws.

C. Fuselage, Body, and Landing Gear

A typical build of the Top Flite 1/5th-scale Cessna 182 Skylane model would necessitate the installation of mock seats resembling those in the full scale 182. This seating, however, was not needed for flight testing as the model needed to be functional but did not need to have a scale interior. Only the external geometry of the model would have an appreciable effect during flight testing and the omission of the mock seats would allow for easy component placement and maintenance. Despite not installing the mock seating included in the ARF kit, many tasks and modifications were necessary for both the fuselage and landing gear.

The landing gear for the model came in several major parts: three wheel pants, two main gear struts, one nose gear wire, three rubber tires, as well as several screws and adapter pieces. The main landing gear were the first to be installed. The main landing gear pants were trimmed as to fit the axles protruding from the struts. As the axles were overly-long, they were trimmed to an appropriate length by use of a Dremel tool and bench grinder. Following this, the struts were slotted into both the wheels and wheel pants and secured with screws. Next, holes were made in the fuselage skin, through which the struts were inserted and then screwed to an internal wooden bulkhead.

Following the installation of the main landing gears, the nose landing gear was installed. This began with with trimming of the nose gear pant and wire. This was necessary as the unmodified nose gear wire caused misalignment of the tire. The wire was threaded through the tire and pant and held in place with screws and a nylon strap. Next, nose gear bearing block halves and a steering arm were inserted onto the wire. The block halves were screwed onto a wooden bulkhead on the firewall while the steering arm was left free to rotate. A pushrod and tubing were attached to the steering arm on one end and to the spare arm of the servo controlling the rudder on the other. The hole in the firewall was fireproofed with epoxy. The bottom edge of the fuselage firewall was trimmed with a Dremel tool as to allow for rotation of the nose gear wire.

After the landing gear were assembled and installed, modifications were made for the powerplant components (battery, motor, etc.) described in Section D. First, holes were drilled into the firewall, onto which the standoffs and mount for the motor would be attached with bolts. Next, the nose cowl was placed over the assembled motor and trimmed as to fit over a rotating nose gear wire. Positions of the nose cowl and motor were adjusted for alignment, after which the nose cowl was attached to the fuselage with screws inserted into holes drilled into protruding wooden blocks. The spinner backplate, spinner, and propeller provided by the manufacturer were not of the correct size, requiring that new parts be ordered. The new spinner backplate was screwed onto the motor shaft, followed by the propeller, and then by the spinner cone.

After these modifications and those mentioned previously, wing struts as well as plastic mock windows and windshields were installed to complete the build. Pre-made holes in the wings and fuselage bulkheads were exposed. Then, taking care to maintain perfect alignment of the wing and fuselage, each wing strut was screwed to a side of the fuselage at one end and the corresponding wing at the other. To complete the fuselage, plastic windows and windshields were cut from their molds and fit into their respective holes. After fitting, the windows and windshields were attached to the fuselage. For the four cabin windows, this required application of wood glue to the edges of the window followed by insertion into the hole. The rear windshield was installed like the cabin windows, but needed to be supported as it dried since it was inserted from below.

D. Propulsion System

The motor used in the build of the stock model was an A50-14 L V3 manufactured by Hacker Brushless Motors. The specifications for this motor, as per the manufacturer, are shown in Table 2. The motor was mounted inside the nose of the fuselage by means of a motor mount and four standoffs secured by bolts. The motor mount and standoffs provided by the manufacturer were imprecisely made in that the screw holes in the motor mount did not match the pre-cut holes in the firewall. Additionally, the provided standoffs had holes much too large for the bolts intended to hold the structure in place. This required designing and machining of a new motor mount and four new standoffs. These parts were then used in mounting the motor to the aircraft. Engineering drawings of the new machined parts can be seen below in Fig. 6.

A Pro Lite V2 battery from Thunder Power RC was used for the Top Flite model. A lithium-polymer battery, the Pro Lite V2 is an 8-cell pack that carries a 6600 mAh current and has a voltage of 29.6V. The battery was significantly larger than the recommended battery in terms of both capacity and size. This would allow for a longer maximum flight time and the increase in weight would help later during the dynamic scaling process. However, this meant that the battery would not fit under the servo tray within the cabin as the build manual recommended and was instead placed inside the nose of the aircraft just aft of the firewall and then secured to the fuselage with Velcro strips, as seen in Fig. 4. This change in battery placement would result in a change to the mass distribution, which coincidentally changed the mass distribution and inertias to values closer to the dynamic scaling target values. An image of the motor can be seen below in Fig. 5.

Table 2. Specifications for Hacker A50-14 L V3 brushless motor.[6]

Max. Power Range	1650 W
No-load Current (at 8.4V)	1.0 A
Internal Resistance	0.025 Ohm
Weight	445 g
Outer Diameter	48.7 mm
Length	62.2 mm

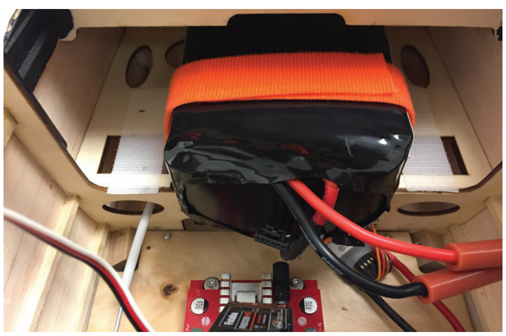


Figure 4. 8S 6600 mAh LiPo battery in fuselage.

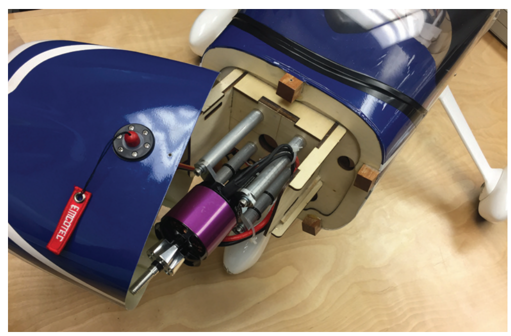
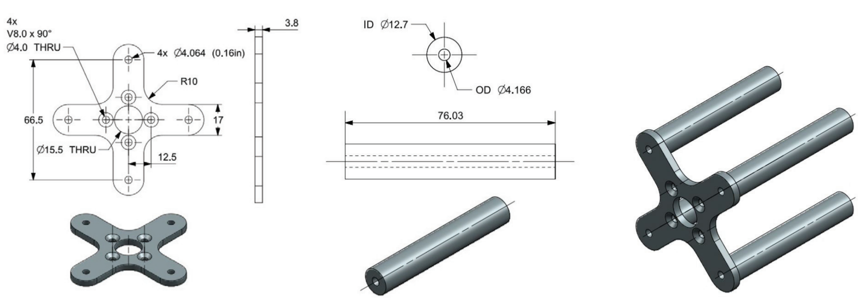


Figure 5. Hacker A50-14 L V3 motor mounted.



(a) (b) (c)

Figure 6. Custom motor mount (all dimensions in millimeters): (a) motor mount, (b) standoff, and (c) completed assembly.

E. Internal Electronic Components and Instrumentation

The major internal electronic components needed for the operation and flight testing of the Top Flite Cessna 182 model were the servos, wireless receiver (coupled with a transmitter), a power distribution system, a flight data acquisition unit, and the pitot probe described in Section A.

The primary type of servo used in this build was the Futaba S3010 standard high-torque ball bearing servo. Weighing 1.5 oz, the S3010 can provide a maximum torque of 90 oz-in and has a maximum speed of 0.16 sec per deg (at 6.0 V).[7] Two of these servos were mounted inside the wings and had wires running to the inside of the cabin, which can be seen in the center of Fig. 2(c). These two servos controlled the ailerons and flaps on the wings. Another three S3010s were attached to a specially-fabricated wooden bulkhead. These three servos controlled the two elevators on the horizontal tail and the rudder on the vertical tail. A Futaba R6008HS was the receiver used in this build. The R6008HS is an 8-channel receiver with a 2.4 GHz frequency. It weighs 0.48 oz and requires 4.8 or 6.0 V of power.[8] Both the R6008HS receiver and all the S3010 servos were connected to a Smart-Fly PowerSystem Sport Plus power distribution system, which has a built-in 6.0V, 5A regulator.[9] Like the servos, the Smart-Fly unit was placed in the cabin and screwed to the specially-made wooden bulkhead. The receiver was mounted on an L-bracket atop the Smart-Fly unit. The servos, receiver, and Smart-Fly unit can be seen in Fig. 7 below.

Also connected to the Smart-Fly PowerSystem Sport Plus and the other internal electronic components was an Al Volo FDAQ data acquisition system.[10] This FDAQ unit has a data sampling rate ranging from 100 to 400 Hz. The unit has an onboard nine-degree-of-freedom inertial measurement unit (IMU), has 32 analog input channels, 4 servo input serial buses, weighs 5.2 ounces, and can operate in adverse temperature conditions. This FDAQ unit was used to acquire flight test data for the dynamic scaling research project for which this build was a small part. The FDAQ system was mounted just aft of the main landing gears, as can be seen in Fig. 8. Specifications for the Al Volo FDAQ are shown in Tables 3 and 4.

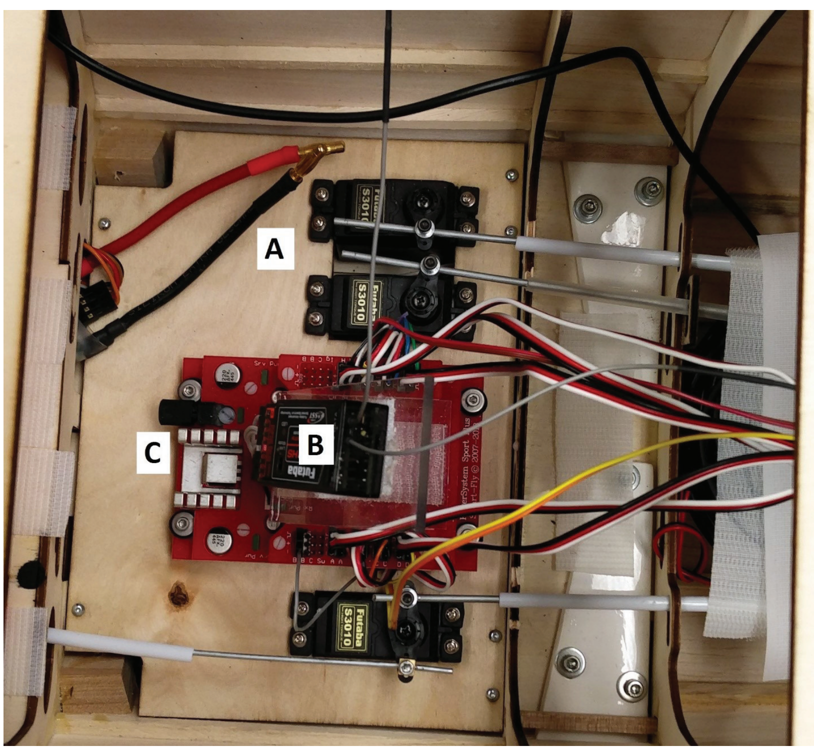


Figure 7. Internal electronic components housed in the forward cabin: (A) Futaba S3010 servos, (B) Futaba R6008HS receiver, and (C) Smart-Fly PowerSystem Sport Plus power distribution system.

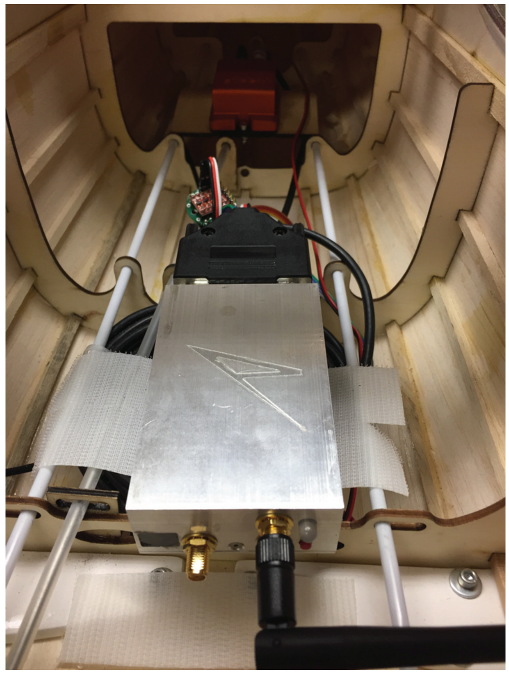


Figure 8. The Al Volo FDAQ flight data acquisition system and XSens MTi-G-700 inertial measurement unit in the rear cabin.

Table 3. Al Volo FDAQ flight data acquisition system performance specifications.

Sensors	
Inertial sensors	3-axis, ±5 g accelerometer 3-axis, ±300 deg/s gyroscope
Magnetometers	3-axis ±750 mG and 3-axis ±11 G
Altimeter (barometric)	1 ft resolution
Airspeed (pitot probe)	5–120 mph, 0.1 mph resolution
GPS position	Up to 400 Hz (IMU assisted)
Tachometer	Motor ESC based
PWM inputs	Up to 22
Analog inputs	Up to 32x 0-5V 12 bit
Data Handling	
Rate	100-400 Hz
Storage	4-32 GB
Local output	Serial or Ethernet
Radio	900 MHz

Table 4. Al Volo FDAQ flight data acquisition system component specifications.

Data acquisition system	Al Volo FDAQ 400 Hz system
Inertial and Flow Sensors	
Inertial measurement unit	XSens MTi-G-700 AHRS with GPS
Airspeed probe	EagleTree Systems pitot-static probe
Airspeed sensor	All Sensors 20cmH2O-D1-4V-MINI differential pressure sensor
Motor Sensors	Castle Creations Serial Link connected to FDAQ motor sensor input
Power	
Regulator	Built into FDAQ
Battery	Thunder Power ProLite 3S 1350 mAh

F. Calibration

Upon completion of the build, it was necessary that the model be checked for proper alignment and symmetry. As discussed earlier, alignment of the horizontal tail and wing was checked through measurement of distances between tips. When the control surfaces were connected to their servos, calibration was needed to set adequate control throws for each control surface. An aircraft protractor was placed at the trailing edge of the widest part of each control surface to measure its response to servo activation. If a control throw did not fall within the recommended range, the transmitter would be used to tune and trim the response until it did. Table 5 below lists the manufacturers recommended control surface throws for high and low rates of control. Fig. 9 demonstrates the process of calibration performed for this build.

Table 5. Recommended control surface throws for different rates.

Control Surface	High Rate	Low Rate
Elevator	1-1/16”, 15° up & down	3/4”, 10° up & down
Rudder	1”, 15° right & left	5/8”, 9° right & left
Aileron	5/8”, 17° up & down	1/2”, 14° up & down
Flap	2”, 36° down	1”, 18° down

Figure 9. Calibration of control surfaces.

With the entire aircraft assembled and control surfaces calibrated, the aircraft was balanced and the center of gravity (CG) determined. The manufacturer specifies that the aircraft CG should be at 4-5/16 in. aft of the wing leading edge. Two supports were placed below each wing at the desired CG location and movable internal components were shifted until balance was achieved for the desired CG. With the completion of this vital step, the build process of the Top Flite 1/5th-scale Cessna 182 Skylane model was concluded.

III. Dynamic Scaling of Mass Properties

Dynamically scaling a model aircraft is based on a set of scaling relationships dependent on a few main factors: the scale of the model, the ratio of air densities at full-scale and model altitudes, as well as the ratio of kinematic viscosity values at both altitudes. These dynamic scaling relationships are outlined in Table 6. Subsequently, dynamically scaling the model mass properties requires information about the mass properties of both the model and full-scale aircraft as well as flight conditions for both.

Table 6. Dynamic scaling relationships.[1]

Linear Dimension	n
Relative Density	1
Froude Number	1
Angle of Attack	1
Linear Acceleration	1
Weight/Mass	n^3/σ
Moment of Inertia	n^5/σ
Linear Velocity	$\sqrt{n}$
Angular Velocity	$1/n$
Reynolds Number	$n^{1.5}\nu/\nu_o$
Time	$\sqrt{n}$

Table 7 lists a summary of weights for different components of the full-scale Cessna 182 which, when combined with approximate locations aft of the nose, aid in the development of an approximate mass distribution model. To model the weight distribution of the 182 during landing, a phase of flight during which upset and stall are more likely, the fuel tanks were modeled as empty, yielding an effective full-scale minimum gross takeoff weight ($TOGW_{min}$) of 1,961 lb. The configuration corresponding to empty fuel tanks has a center of gravity (CG) that falls within the operational envelope, and is thus valid. Most existing flight data for the full-scale 182 is for an altitude of 5,000 feet above ground level (AGL), which was used as the altitude for which density and kinematic viscosity values were taken.

Table 7. Cessna 182 Skylane dimensions, weights, and moments of inertia.[11]

Component	**Weight** [lb.]	CG_x [ft.]	CG_y [ft.]	CG_z [ft.]
Wing Group	235	8.449	0	5.900
Empennage	62	23.524	0	5.055
Fuselage	400	7.280	0	3.000
Landing Gear	132	7.290	0	1.200
Engine	417	3.000	0	3.800
Fuel	0	8.449	0	5.900
Payload	715	8.400	0	3.700

The Top Flite Cessna 182 Skylane model described in Section II was nominally 1/5th (20%) scale of the actual aircraft. With a wingspan of 6.75 feet, the stock Top Flite aircraft was actually an 18.75%-scale model of the full-scale. Table 8 lists the total as well as component weights for the Top Flite model. An altitude of 400 feet AGL was chosen for the purposes of model flight testing, resulting in an atmospheric density ratio of 0.872 between the model and full-scale. Application of the density ratio as well as the geometric scale to the dynamic scaling relationships in Table 6 yielded desired mass and moment of inertia values for a dynamically scaled 18.75% scale Cessa 182 model as tabulated in Table 9.

Scaling the approximate full-scale component weights and locations summarized in Table 7, a target mass distribution was developed for the 18.75%-scale model. Some of the resultant component weights, locations, moments of inertia, and errors are tabulated in Table 10. As with the full-scale 182, the target dynamically scaled model was modeled as

Table 8. Completed Top Flite Cessna 182 Skylane model dimensions, wights and moments of inertia.

Geometric Properties	
Overall Length	64.0 in (1630 mm)
Wingspan	81.0 in (2060 mm)
Wing Area	898 in^2 (57.9 dm^2)
Wing Aspect Ratio	7.47
Inertial Properties	
Weight	
Empty (without Batteries)	12.08 lb (5.48 kg)
8S 6.6 Ahr LiPo Main Battery	2.74 lb (1.25 kg)
RC and Avionics Batteries	0.49 lb (0.22 kg)
Gross Weight	15.31 lb (6.94 kg)
Wing Loading	39.3 oz/ft^2 (120 gr/dm^2)

Table 9. Scale Cessna 182 Skylane target weights and moments of inertia.

Characteristic	**Value**
W	17.09 lb
I_{xx}	0.252 slug-ft^2
I_{yy}	0.358 slug-ft^2
I_{zz}	0.523 slug-ft^2

having empty fuel tanks. This reduced the final total weight of the eventual target model, which was necessary as not doing so would result in a model too heavy for the chosen motor.

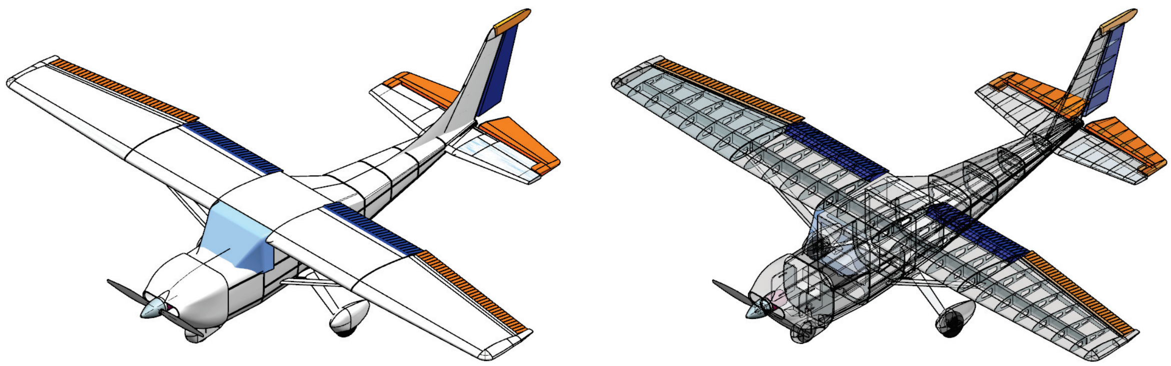
Table 10. Scale Cessna 182 Skylane target component masses, locations, moments of inertia, and error.

Component	**Weight** [lb.]	CG_x [ft.]	CG_y [ft.]	CG_z [ft.]	I_{xx} [lb-in^2]	I_{yy} [lb-in^2]	I_{zz} [lb-in^2]
Wing Section 1	0.44	1.58	-2.76	1.09	494.94	9.16	486.05
Wing Section 2	0.89	1.58	0.00	1.09	18.05	18.32	0.27
Wing Section 3	0.44	1.58	2.76	1.09	494.94	9.16	486.05
Horizontal Tail	0.20	4.26	0.00	0.68	0.04	0.04	217.80
Vertical Tail	0.27	4.59	0.00	1.05	4.36	4.36	359.89
Fuse. Section 1	0.38	0.44	0.00	0.69	0.02	0.02	65.80
Fuse. Section 2	1.66	1.58	0.00	0.69	0.08	0.08	0.54
Fuse. Section 3	0.98	3.00	0.00	0.69	0.05	0.05	302.54
Powerplant	4.12	0.66	0.00	0.71	0.00	461.38	461.38
Fixed Equip.	1.31	1.37	0.00	0.62	1.55	7.19	5.64
Calculated [slug-ft^2]	17.339	–	–	–	0.236	0.363	0.566
Desired [slug-ft^2]	17.090	–	–	–	0.252	0.358	0.523
Error [%]	1.404	–	6.307	–	–	1.415	8.292

As the errors in Table 10 demonstrate, this mass distribution is a relatively accurate model of the target values defined by the dynamic scaling factors. Errors below ten percent are considered adequate. Since the overall goal for the project is to accurately represent the Cessna 182 in upset and stall states, the pitching moment of inertia (I_{yy}) should be as close as possible to its target. From the weight breakdown and component placement, I_{yy} was satisfactorily close to its target value (1.4% error). From this exercise, the involved undergraduates gained experience relevant to mass and weight property management. Mass and weight management is important in the development of stable, controllable aircraft and as such the undergraduate assistants in this project acquired more skills applicable in both academic research and industry.

IV. Weighted CAD Model

To determine the effects of modifying the stock model without having to physically modify it, a CAD model was developed using Siemens NX 10.0, shown in Fig. 10. The first step in creating the CAD model was to obtain measurements for all R/C aircraft component dimensions and masses. Since the R/C model was purchased as an Almost-Ready-to-Fly kit, it was impossible to obtain measurements of the internal structures without disassembling the model. Therefore, estimations were made based on a build manual from Top Flite.[5] This build manual, though not for the ARF kit used in the build, was for the same aircraft and was thus deemed acceptable for use. The build manual also included schematics and the required materials for interior structure of the wing shown in Fig. 11, which were modeled and incorporated into the CAD model. Some of the smaller components were not modeled as individual parts as their contribution to the moments of inertia were minor; they were instead assumed to be part of the structure.



(a) (b)

Figure 10. Isometric views of the baseline GA-USTAR aircraft: (a) completed and (b) internal structures and interior.

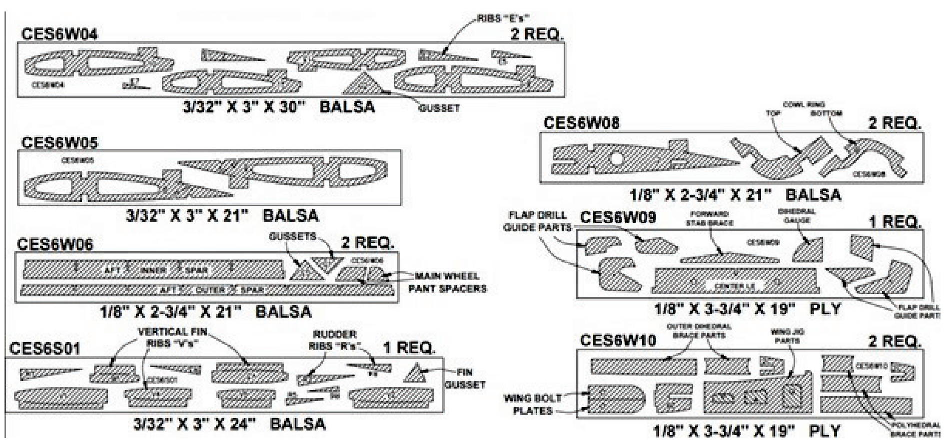


Figure 11. Wing and tail ribs and spars plans.

Moment of inertia and mass values from the model are shown in Table 11, where these values were compared to the dynamically-scaled target values. These values need to be validated using an inertia testing rig. Since the moment of inertia of the model was found to be higher than the target values, modifications to the model were deemed necessary.

Table 11. Unmodified aircraft measurements.

	NX Top Flite Model	**1/5th Dynamically scaled model**	**Difference** [%]
W [lb.]	14.8	17.0	12.94
I_{xx} [slugs-ft2]	0.5776	0.349	65.50
I_{yy} [slugs-ft2]	0.7475	0.495	51.01
I_{zz} [slugs-ft2]	1.209	0.723	67.22

V. Flight Testing

Baseline flight testing was conducted to evaluate in-flight behavior and performance. Conducting a flight test required a list of maneuvers and protocols to create a controlled experiment, as a pilot must be briefed regarding the maneuvers that need to be conducted. In-flight battery voltage monitors were connected to the lithium-polymer battery to verify that each of the battery cells had enough power for the flight. The model was then assembled at the field, where the wing and struts were attached as shown in Fig. 12(a). The battery was then connected to the motor and then the safety switch was removed from the aircraft, allowing the propeller to rotate freely. Propeller testing was conducted on the ground while the voltage was monitored to determine if the battery cells could handle the motor load as shown in Fig. 12(b).

(a) (b)

Figure 12. Preflight procedure at the field: (a) wing and strut assembly of the aircraft and (b) pre-flight motor testing.

After the verification process, the pilot took the aircraft to the runway while an observer monitored the battery voltages, relayed flight maneuvers, and timed the maneuvers in sync with the data logger for post flight processing as shown in Fig. 13. The flight maneuvers conducted for the first flight began with the pilot trimming the model, reducing pilot input required for straight and level flight.

Figure 13. Pilot flying the aircraft with observers relaying and timing flight maneuvers.

VI. Conclusions

As part of a larger research endeavor studying the upset and stall behavior of general aviation aircraft, undergraduate research assistants at the University of Illinois at Urbana-Champaign aided in the development of a dynamically scaled model of a Cessna 182 Skylane. Their contributions began with the building of a stock Top Flite 1/5th scale model with modifications to include instrumentation for subsequent flight tests. Necessary modifications and developments were determined to scale and accurately represent mass, and inertia properties of the full-scale aircraft. This made use of many tools, including test rigs for baseline data acquisition and CAD for modeling. These contributions laid a foundation from which a dynamically scaled model can be completed and used to investigate the flight characteristics of general aviation aircraft.

The project was of great educational and developmental value for the undergraduate contributors. Through the project, they became familiarized with tools and processes common in both academia and industry. Several individuals were involved, subsequently providing the undergraduates with valuable experience working on a multifaceted project with a large team. This project also saw the development or refinement of the undergraduates skills, ranging from manufacturing, to experimental validation, to technical writing. As the students continued working on this project, they also learned how to conduct research independently, preparing them for graduate level research.

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