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Team 507: SAE Aero Design: Aero Propulsion Team

Operation Manual

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1. Overview

1.1 Project Overview

SAE Aero Design competition is an aircraft design competition for college students which is held annually. This year the entry from our school is comprised of two teams. T508 is the geometric team and we, T507, are the aero propulsion team. The overall objective is to design and manufacture a remote-controlled plane within the rules and regulations of the SAE Aero Design East Competition 2021. The objective of the aero propulsion team is to ensure that the plane takes off, completes the flight path, and lands safely while carrying a payload. We included 2 innovative designs in our plane. We added a canard wing, which is an extra wing added in front of the main wing to ensure that our plane will take off easily. We also decided to use a belt-gear system to operate control surfaces, which are used to control the plane when it is in the air. Our plane has 3 wings and weighs 12 pounds without cargo. We estimate our plane to take off in just under 55 ft.

1.2 Collaboration with the geometric team (T508) and role played by the RC club

As this year's project is a combined effect of the aero team and the geometric team, we made sure to collaborate with T508 and held all team meetings, except for a handful, with them. While we focused on aerodynamic and propulsion calculations, we checked with T508 dimensions of our design to ensure that those parts can be made. This is very important as they have information on 3-D printing, and some parts could be difficult to print even if their dimensions are within restrictions. Hence, we recommend checking every design with the geometric team (if the geometric system is handled by another team). Furthermore, T508 were in charge of contacting the Seminole R/C club, who provided useful information during the design stage. We found out this to be very helpful, as they provided key information on designing the landing gear of our plane. Furthermore, they provided the pilot and the controller for our plane. We recommend contacting the RC club early for the future teams as well.

2. Model

2.1 Propulsion

Onyx22.2V 4000mAh 6S 30C LiPo Battery coupled with a power limiter to supply power to the motor. E-flite Power 90 Brushless Outrunner 325Kv high torque motor used to spin the propellor. The propellor featured on this plane is an APC 18x10E. This propellor has a diameter of 18in and a pitch of 10°. All these components come together to make the propulsion system for our plane, producing approximately 222 lbf of the thrust.

2.2 Fuselage and Vertical Tail

The fuselage and tail configuration were modeled after the Lockheed Martin X-55. Particularly, the curvature of the back of the fuselage into the tail, and the T-tail layout. The drag coefficient for the body of the X-55 was used for aerodynamic calculations. The payload is secured in the fuselage. One top half of a fuselage section can be removed by unscrewing two bowties. The soccer ball is placed in a bowl towards the front of the hatch. The box weight payload is screwed down to a plate at the back of the hatch, where the fuselage begins to taper into the tail.

2.3 Wing Layout

The plane features three lifting surfaces, canards, main wing, and tail. The wings closest to the leading edge are the canards. These smaller wings provide lift and help prevent stalling. The canard airfoil will reach its stall angle of attack before the main wing. Then the plane will start to tilt down, however the lift provided by the main wing will stabilize the body pulling the nose back up providing a natural feedback loop for the plane. The main wing is located 25 inches from the leading edge of the plane and provides two thirds of the lift of the plane. It has the longest chord length and wingspan of all the wings, giving it the largest surface area. The canard is positioned on the bottom third of the fuselage, the main wing is in the top third, and the tail lays on top of a vertical tail so all three surfaces are on different planes.

2.4 Control Surfaces

There are control surfaces located on the trailing edge of the main wings, rudder, and tail. The ailerons on the main wings help steer by controlling roll stability. When performing a bank maneuver, the inner aileron deflects down, and the other angles upward. The ailerons have a differential deflection setting of 8:20. This means that when both are fully rotated, the downward pointed aileron is at an 8-degree angle while the upward facing aileron is at 20 degrees. The rudder is found on the vertical tail wing and helps control yaw. The rudder can rotate 25 degrees either direction, it can be used to turn, as well as combat crosswinds. The elevator is placed on the tail to control pitch. It can deflect 30 degrees and will be used to help the plane takeoff and land.

A belt and a gear system are used to operate control surfaces. We used a GT2 belt and gear system, which can be accessed using the link here. The belt was cut to into smaller pieces to create the correct amount of tension and soldered together. Make sure to put the soldered part in a section that doesn't go over a gear.

Figure 1: Belt and Gear

2.5 Landing Gear

The landing gear design is based on research done on typical landing gear designs for RC planes and information provided by the Seminole R/C club. The landing gear needs to create at least 3 inches of ground clearance for the propeller. Our plane has around 4 inches of ground clearance. We used a tricycle landing gear layout with one wheel at the front and two wheels at the back, opposed to reverse tricycle design which has the reverse layout to the layout mentioned above. As the center of gravity of our plane is towards the back, the layout we use creates a more even weight distribution. We placed our landing gear to have a 1:2 weight distribution between the front landing gear and each back-landing gear. It is important to place the back-landing gear closer to the center of gravity as the back of the plane touches the ground first during takeoff and this layout reduces the chance of our plane tipping over during landing. The canard layout makes sure that the plane has a moment towards the ground during landing, reducing the load on the back-landing gears and reducing the chance of tipping over. Due to these reasons, we recommend a tricycle landing gear layout.

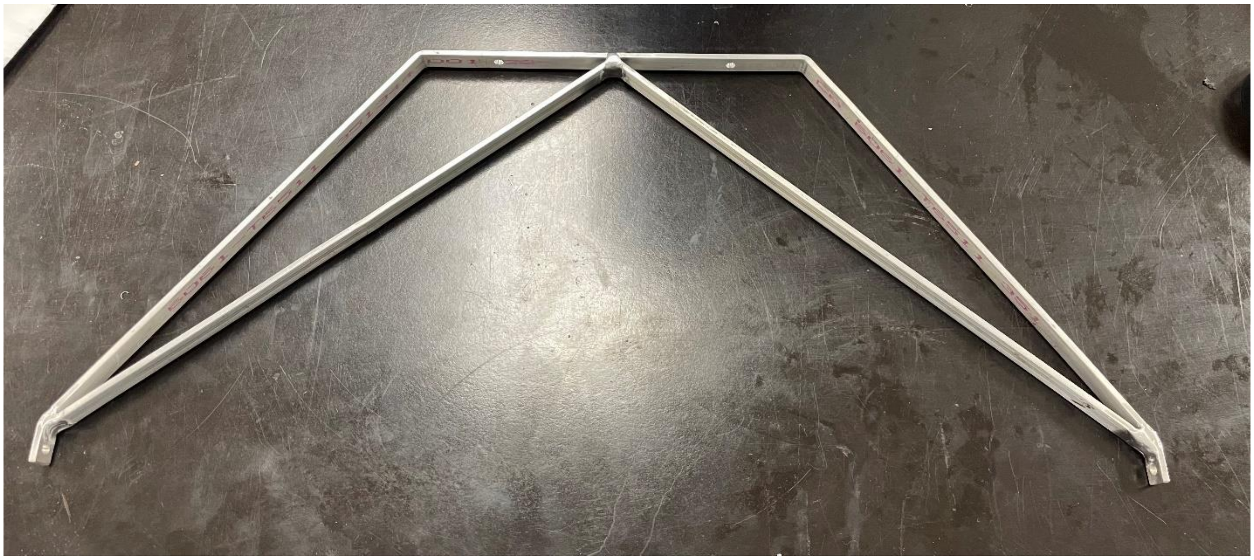

Figure 2: Rear Landing Gear

For information on integration, read the operation manual written by T508 (geometric team). For calculations related to the design process, including stability calculations, center of gravity determination, and determining dimensions of the plane, access our calculations here. Visit our one drive folder for more details on the overall project through here.

3. Power Setup

3.1 Controller

Our plane was set up and programmed with the Futaba T6J transmitter. This transmitter is linked to the Futaba 6J 6-Channel S-FHSS system receiver and features 6 different channels. The channels were used for our ailerons, elevator, rudder, and front landing gear for our design this year. Shown in the figure below are the main functions of the plane and which part of the transmitter controls it.

Figure 3: Controller and its controls

To program the remote, hold the button below the thrust-cut button for approximately 3 seconds until you hear a long beep. The menus on the display can be navigated with the silver '+' and '-' arrows located on the right side of the display. To see what each menu does more in-depth and how to alter it, the manual for the controller is located in the following link: [books folder in T507 One Drive.]

For the actual flight, we recommend using a controller and a receiver that the pilot is comfortable with. For more information about the controller and programming the controller, please contact Fredrich Mursch from the Seminole R/C club through email: fredrichmursch@aol.com

3.2 Wiring

The wiring of the plane begins at the battery, near the front of the plane. This position was chosen to avoid any unnecessary resistance from the battery to the plane's motor as any extensions on those wires increase the resistance in the circuit and decrease the voltage drop to the motor. The battery is a part of a closed circuit that includes the E-flite Power 90 Brushless motor, the ZTW Gecko 85A Electronic Speed controller, the power limiter (1000W), and the Futaba 6J 6-Channel S-FHSS system receiver. From the receiver, wires that connect to the servos in the main wings will flow along the bottom of the fuselage and split around the battery and cargo. One path will lead to the servo in one of the main wings and the other path will lead to the servo in the other main wing and to the remaining servos in the rudder and tail. In the main wings, there are pathways printed into the airfoil that the wires will go through to reach the servos. The wires going to the rudder and tail will be placed along the vertical side of the fuselage of the plane extending to the rear of the plane. Pathways in the tail will lead them to the servos that are in the rudder as well as the elevator servos in the tail. The elevator servos in the tail will be paired using servos splitting wires. Due to the wiring system being a closed-circuit system, we implemented a red arming plug located on the back of the plane; used for safety to turn off the plane. This red arming plug is coupled with the throttle kill switch on the controller, so the user can disable the plane manually or remotely. Shown below is a wiring diagram showing what each receiver port each of the plane's functions correspond to.

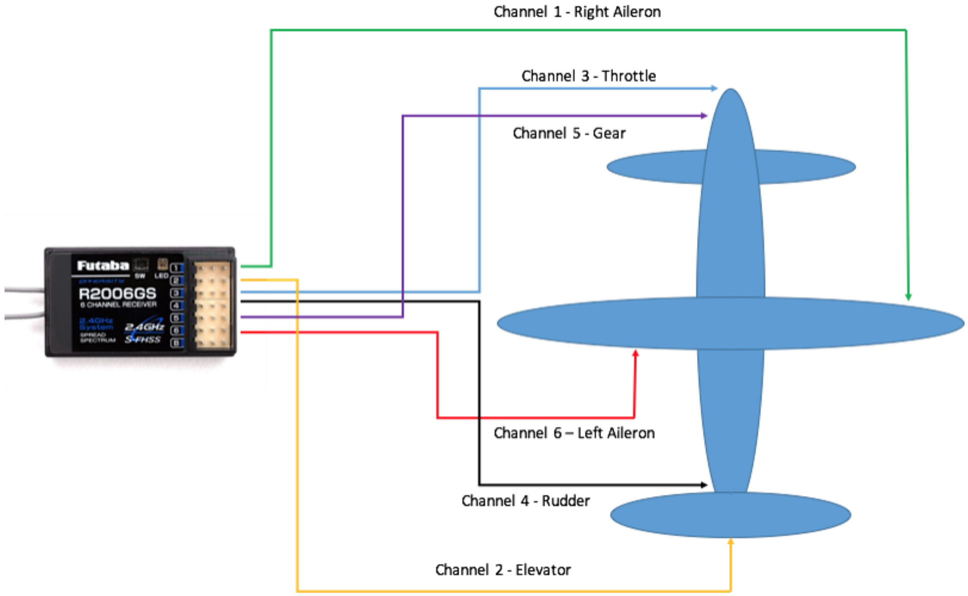

Figure 4: Wiring setup

4. Validation

Validation is a very important step in making the plane. As the design process involves innovative concepts and an intricate electrical setup, it is important to ensure that the plane performs as expected before the test flight.

4.1 Power Test

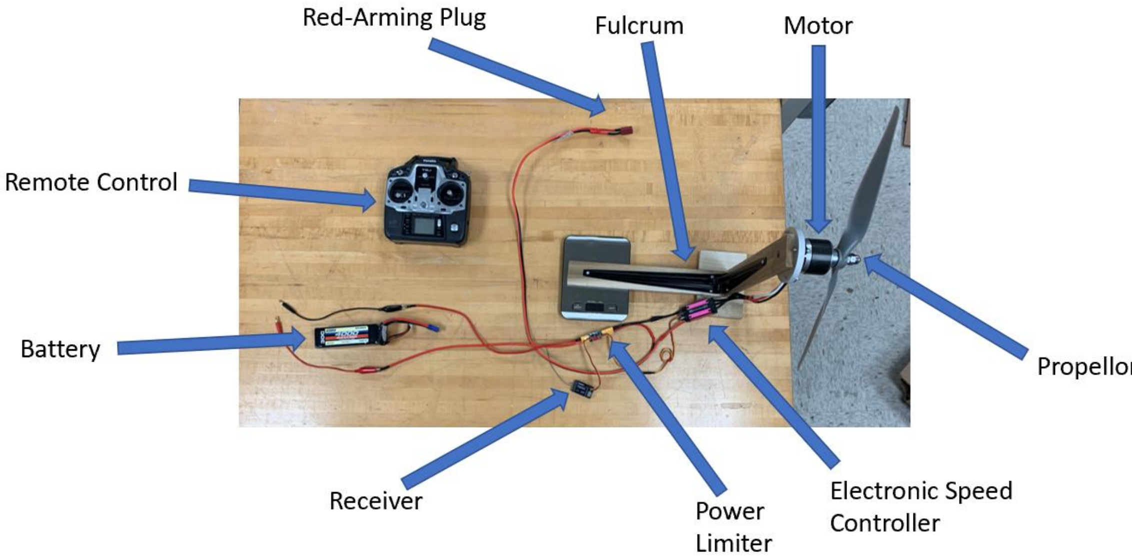

Figure 5: Propeller Test Setup

The above figure shows the power test setup for the propeller. The propeller and the motor are attached to a L-shaped fulcrum, which is resting on a scale. The wiring procedure is explained in section 3.2 above and the control procedure is explained in section 5.1 below.

4.2 Wind Tunnel Test

We recommend a wind tunnel test for a scaled down model of the actual aircraft. The CAD for the model can be found here. Contact Dr. Rajan Kumar to gain access to the subsonic wind tunnel at Florida Center for Advanced Aero-Propulsion (FCAAP). At minimum, conduct a qualitative study at different angles of attack (5 degrees and 12 degrees at least) to double check stalling properties of the plane. As light weight PLA prints often could give inconsistent prints, the aerodynamic properties of the plane could change from theoretical calculations to the actual plane. Therefore, make sure that the CG for the model is still within the stability margin for the plane (+/- 2 inches from the location market on the fuselage). If possible, try to do a quantitative wind tunnel test with simple lift and drag values, to ensure that the plane produces the same lift and drag as expected. Both lift and drag should be slightly higher than the calculated value, as interference drag, fuselage lift etc. is found through testing and hard to be estimated through calculations. Shown below is the setup for the wind tunnel model. Note that only the scaled down model and the attachment to it must be printed. The rest of the parts in the assembly is available in the wind tunnel lab.

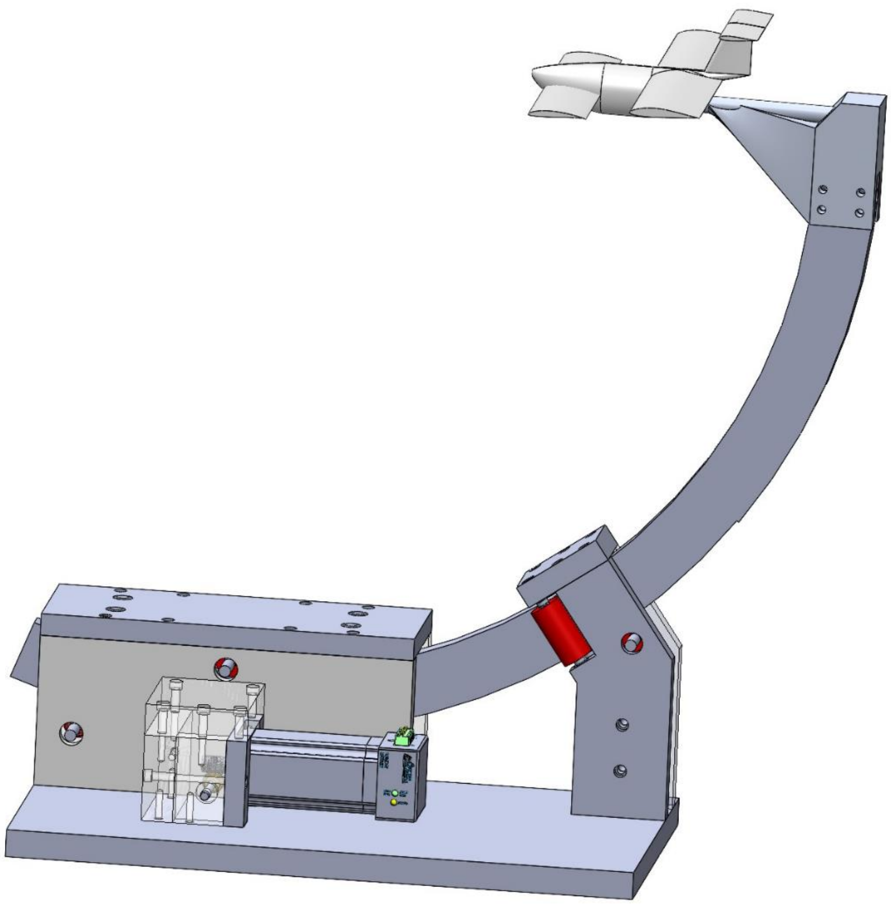

Figure 6: Wind Tunnel Setup

5. Operation

5.1 Start-up

1. Ensure that the receiver is powered on by connecting the wire coming out of the power limiter to the ‘Batt’ channel on the receiver while the battery is connected, and the red arming plug is armed. A red LED should light up when connected.
2. Remove the wire coming out of the power limiter from the ‘Batt’ channel then connect it to channel 3 (throttle channel). Make sure all connections are secure and all wires face the right way. (polarity is correct).
3. Power on the transmitter.
4. When the beeping ceases and a long sound plays, the airplane is powered on and ready to fly.

5.2 Pre-Flight Check List

1. Battery/Transmitter Voltage (plane and controller)
    a. Making sure that the battery is charged, and the transmitter is receiving power
2. Check Surfaces
    a. Making sure that all butterflies are tightly secure and there are no cracks or disturbances on plane’s surface
3. Check Airframe
    a. Making sure that the plane is structurally sound before take-off
4. Check Propeller
    a. Make sure that the propeller is secure on the plane
5. Check Landing gear
    a. Make sure that the wheels can move freely, and they do not wobble when moving

6. Check Motor
    a. Make sure it is getting power and can spin freely
7. Check Servos
    a. Check all servos to make sure they are moving in the right direction
8. Check Center of Gravity
    a. Balance the plane with all the components

For further information, use the pre-flight checklist available via this link.

5.3 Flight Control

A certified Academy of Aeronautics (AMA) pilot should fly the plane. The plan was to ask a pilot at the competition to fly. For flights/test flights here in Tallahassee, contact the Seminole R/C club for assistance, including for a pilot or finding a runway.

5.4 Shutdown (Including Emergency Shutdown)

When plane is completely stationary, switch off the remote and then remove the red arming plug before disassembling the plane. For information regarding disassembly, read the operation manual written by T508 (Geometric Team).

In case of an emergency, there are 2 methods to shut down the plane. If the plane is flying, it is recommended that the "thrust kill switch" on the remote is pressed. It is located left to the screen (as shown in figure 1 above). Following this, the pilot should still be able to glide the plane to the ground with control surface movement. Even if that is not possible, the geometry of the plane should allow it to glide to the ground.

If the plane is on the ground (including after thrust kill and glide mentioned above), the red arming plug placed in the bottom tail of the plane, in the first tapered section of the fuselage, should be removed. This would stop the current flow. Following this, the plane should be safe to be examined closely.

6. Troubleshooting

As the manual was written before the flight, the following issues and troubleshooting methods are based on the design and integrations, and possible errors that could arise during the flight.

6.1 Controller and Receiver

Issue: The controller is not syncing with the receiver, even though the right procedure is followed.

Solution: The most likely reason is that the controller is set to the wrong receiver frequency. Use the frequency knob in the top center of the controller to set it to the left most channel setting, which is related to our receiver. More information can be found on the controller manual here.

6.2 Servos and Control Surfaces

A manual for the KST X-10 Wing servos we used can be found here. A link to the belt used can be found here.

Issue: Servo does not rotate the amount commanded using the controller.

Solution: The servo neutral position is incorrect. Connect the servo to the trust channel (as that allows for easier control while adjusting the neutral position). When the controller is at the 50% input position, the servo should be at neutral. This can be checked by using a servo head. If not adjust the servo head so that it is at neutral position. (Make sure to do the same with the control surface to servo connection method used later in the project).

Issue: The belt slips from the gears

Solution: With the help of the geometric team, design gears with small adjustments to the standard GT2 gear pitch diameter and pressure angle found here. Then connect a gear to a servo and a another to a rotational axis. Initially try to just rotate the gear with the belt. Make sure that enough pressure is applied where the belt is on the gear and the belt has enough tension. Then run the servo and see if the gear rotates well. Adjust the bearing locations inside the control surface to adjust the tension of the belt. When there is negligible slip of the belt, there is enough tension.

6.3 Validation

Issue: There are small open gaps in the wind tunnel model printed, which could affect the airflow and give invalid data.

Solution: Use "China Clay" and/or tape available in the wind tunnel lab to cover those gaps. They are specifically designed to fill those gaps and not give invalid data. Make sure not to use an excessive amount that would change the geometry of the model.

7. Recommended Improvements

The following are some recommended design changes that we recommend for the future projects. These are based on data collected during the wind tunnel test and based on difficulties we had during the design stage.

7.1 Recommended Design Changes

It is recommended to connect all wing sections via dove tails. Initially considered for structural integrity, the dove tails provide the best from fit between sections. Pieces connected with dove tails are aligned better, with less inconsistency in the creases. Structural support wasn’t considered an issue as there are two spars in the canard and main wings, and one in the tail. It is also important to keep wiring in mind and leave enough place for wires to fit through easily. One print did not have wire holes, and when reprinted the gap was barely wide enough to allow the wire to pass and made it difficult to pull through the entire piece. Landing gear that was rounded at the connection to the fuselage was designed, but constraints from the machine shop prevented its use. This design technique is still recommended, it just needs to be submitted ample time before flight testing.

There is the possibility that the turbulence and vortices produced by the propeller could affect the wings of the plane, especially the main wing. A possible solution is to put the propeller at the back and make the plane a “push plane”. However, it is important to keep the center of gravity in the right range based on the design (just in front of the main wing for our wing layout). Furthermore, the rudder and the tail will have to be redesigned to perform effectively. Another possible design is to have 2 smaller propellers, one on each main wing. A gear system will be required to transfer power from one motor into 2 propellers, with at least one axis translation using gears.

8. Further Reading

We Recommend the books and articles mentioned in the appendix A for further reading, as a guide in designing a R/C plane. The book by Lennon can be used as a guideline for general design, as it goes into detail about typical R/C plane design requirements. We used the book by Anderson for general aerodynamic calculations such as lift and drag, and longitudinal stability calculations. For roll and yaw stability, refer to the book by Sadraey. We highly recommend that book for the entire design process, as that follows a systems engineering approach to aircraft design. Also, refer to the pilot’s handbook regarding setting up control surfaces and their motion.

Appendix A: Resources

Repository links

- Complete OneDrive access
- Aerodynamic Calculations
- Reference Material

If there are any issues accessing these links, contact Adrian Moya (am16bg@my.fsu.edu) or Sasindu Pinto (sp18dy@my.fsu.edu) .

Reference Material

- Anderson, J. D. (2011). Fundamentals of Aerodynamics. In 5. Edition (Ed.). McGraw Hill Publications.
- Lennon, A. (2005). RC Model Aircraft Design. Air Age Media Inc.
- Pilots Handbook of Aeronautical Knowledge. (2017). Federal Aviation Administration.
- Sadraey, M. H. (2013). *Aircraft Design - A systems Engineering Approach.* John Wiley & Suns.

Furthermore, we recommend reading the SAE Aero Design rule book for the relevant year. All these books/papers and the rule book for 2020-2021 can be accessed using the following link to the books folder in T507 One Drive.