# TBF Avenger

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# General info

The Grumman TBF/TBM Avenger was a WWII torpedo bomber, first flown in 1941 and entering service in 1942. It was powered by a Wright R-2600-20 Cyclone radial engine, producing 1,700 horsepower, giving it a top speed of 275 mph (443 km/h). The aircraft had a wingspan of 54 feet 2 inches and a length of 40 feet 11 inches. Its operational range was 1,000 miles (1,610 km) with a service ceiling of 30,100 feet (9,170 meters).

The Avenger could carry a 2,000-pound torpedo or an equivalent bomb load in its spacious bomb bay. Armament included two .50 caliber machine guns and a .30 caliber gun in the rear turret. Known for its durability, over 9,800 units were produced, serving in anti-submarine and attack roles.

The aircraft’s systems, engines and flight model have been developed according to the flight manual. The Microsoft Flight Simulator modern flight model and modern prop model are used entirely by the developer.

The development started with understanding the aircraft systems, operation, and handling characteristics. After that, all parameters were set which had data sources available from the flight manual. The systems, engine and aircraft parameters were set according to the manual and the data found on the internet.

Numerous videos on Youtube were used to understand the handling of the aircraft and these led to the flight test case definitions later in this document.

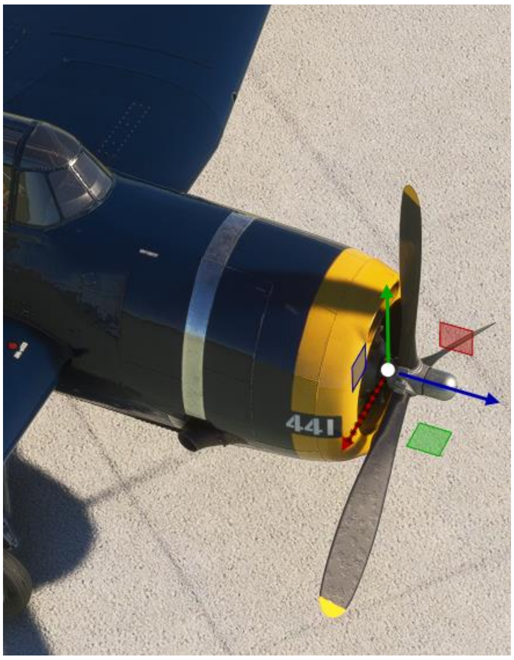
# Files

The scope of the project is to model the aircraft as accurate as possible by using the built-in MSFS systems, engine, and flight model logic. These are defined via configuration files, which are presented here.

## flight_model.cfg

### [WEIGHT AND BALANCE]

- Max. weight is 18000 lb
- Empty weight is 10445 lb
- Reference datum was defined in the MSFS:



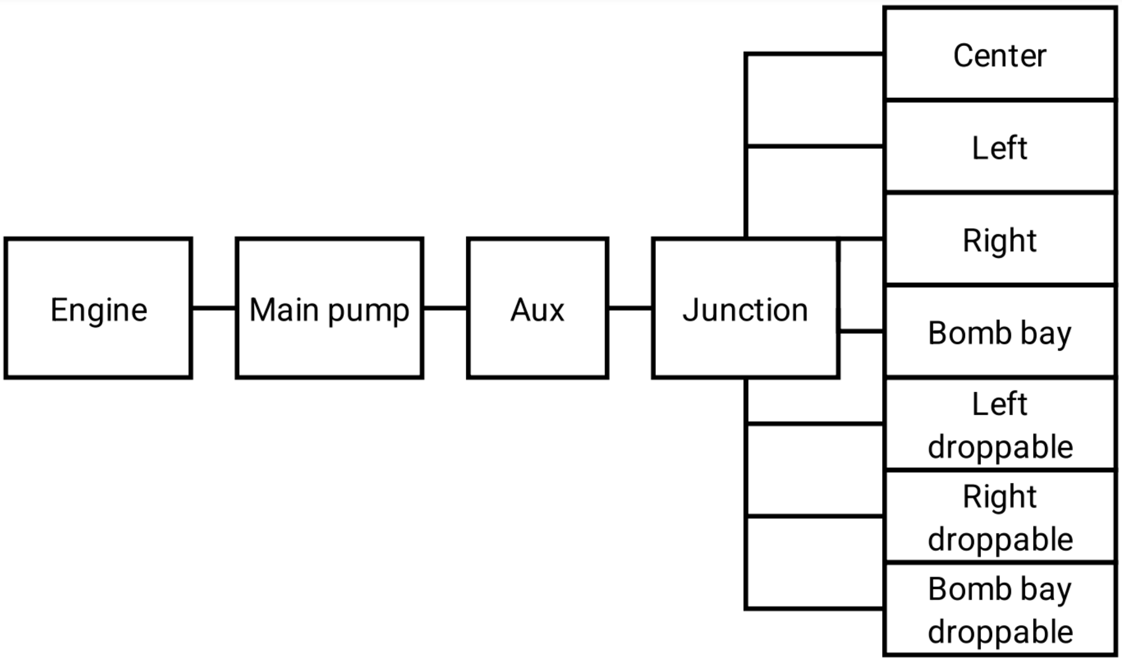

- Empty weight CG position is set in Flight Simulator, the distance from datum will be 12 feet. The forward limit of CG is 13%, the aft limit is 40%.
- Flight characteristics were tuned with a 200lb pilot, a 200 lb copilot and 200lb gunner.
- The CG position is at 29.5% MAC
- Pilot, copilot and gunner stations have been defined, the station positions originate from the pilot handbook and photos of the real aircraft.
- The Moment of Inertia is calculated by the simulator.

### [CONTACT_POINTS]

- The steering angle of the tailwheel is ±90 degrees.
- The tail wheel is a 360° swivel type equipped with a spring loaded self-centering device.
- The aircraft is equipped with independent wheel brakes, which are operated with legs.
- The main landing gears have a radius of 2.67 ft
- The tail wheel radius is 1 ft
- The vertical crash velocity of the wheels is 19 ft/s, and the horizontal is 120 knots.

### [FUEL_SYSTEM]

The fuel system is modelled accurately according to the flight manual. The following drawing depicts the system architecture, which is implemented in MSFS:




*Fuel system MSFS model*

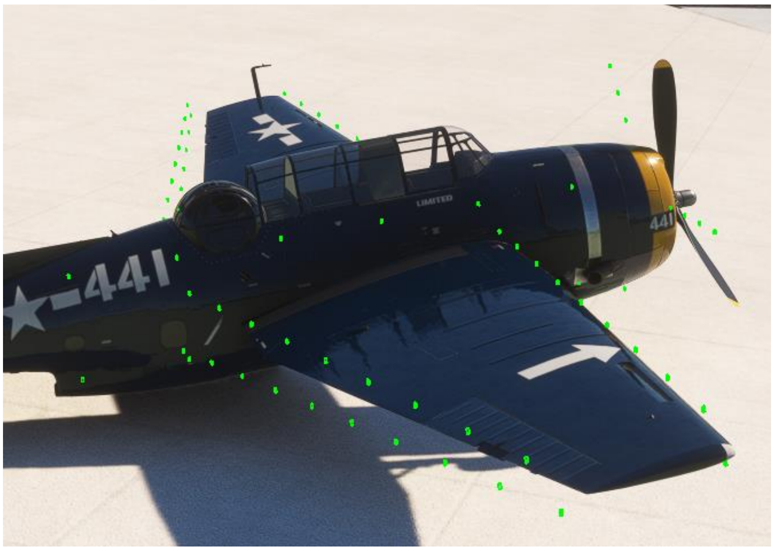
The main fuel tanks (center, left, and right) are located in the wing center section, the bomb bay tank is located in the bomb bay. The droppable tanks are located under the left and the right wing, and in the bomb bay, and they might be dropped when empty.

The aux pump has its corresponding electrical circuit modelled in the electrical systems section of the systems.cfg file.

The fuel lines have been defined to serve the logic of the actual fuel system.

Two procedures have been defined: one for the autostart sequence and one for the auto-shutdown. The procedures set the main pump according to the automatic sequence.

## [AIRPLANE_GEOMETRY]

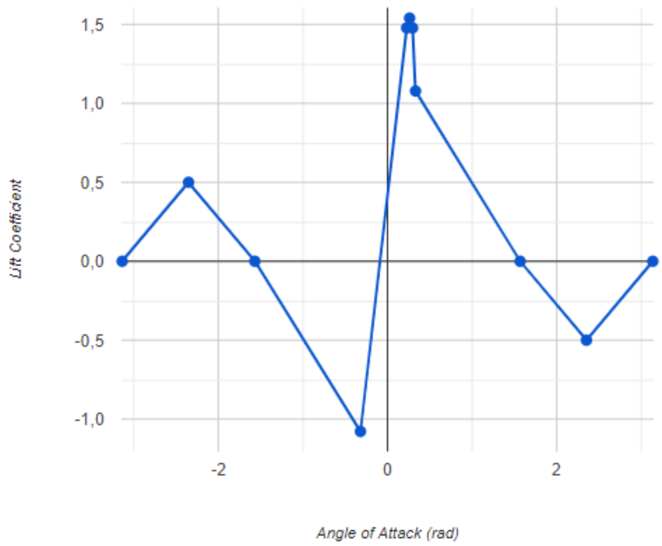


*The wing model*

- Wing camber: 1 degrees, thickness ratio: 0.01
- Average dihedral of 5 degrees is considered
- The datum reference point has been defined according to the drawing shown in the weight and balance section of this document.
- Fuselage length is 40.92 feet
- Flight control surface movement limits:
    - Ailerons: modelled initially with +20/-10 degrees limit (regardless of flaps position).
    - Rudder limit: 25 degrees
    - Elevator limit: +25/-15 degrees
- All areas and other limit values are set according to the flight manual

[AERODYNAMICS]

- Glide ratio of 1:10, and a vertical speed of -1100 ft/min is calculated from 90 kt. For details see Test cases section.
- Climb performance is calculated, see Test cases section.
- The main aerodynamics parameters to tune are the following:
    - lift_coef_aoa_table = -3.15:0, -0.8:-0.916, -0.4:-0.675, -0.2:-1.149, -0.1:-0.679, 0:0.038, 0.20:1.331, 0.23:1.451, 0.26:1.265, 0.29:0.808, 0.31:0.588, 0.4:0.652, 0.8:0.918, 3.15:0




*The angle of attack ( α ) vs lift coefficient ($C_L$) curve*

- lift_coef_at_drag_zero = 0.025; define Cl0, which is the lift coefficient that is generated when the plane produces minimum drag
- drag_coef_zero_lift = 0.033; The zero lift drag polar. Using this value based on the SDK documentation recommendations.
- drag_coef_gear = 0.03 Defines the drag of the gears that will be applied at the location of the gear contact points. (SDK doc recommended value)

[FLIGHT_TUNING]
Flight tuning parameters are most left at 1.0.

[REFERENCE_SPEEDS]

- Stall speed: 72 kt
- Cruise speed: 130 kt
- $V_{NO}$: 250 kt
- Take off speed: 90 kt (approximation)
- Climb speed: 122 kt
- Landing speed: 80 kt

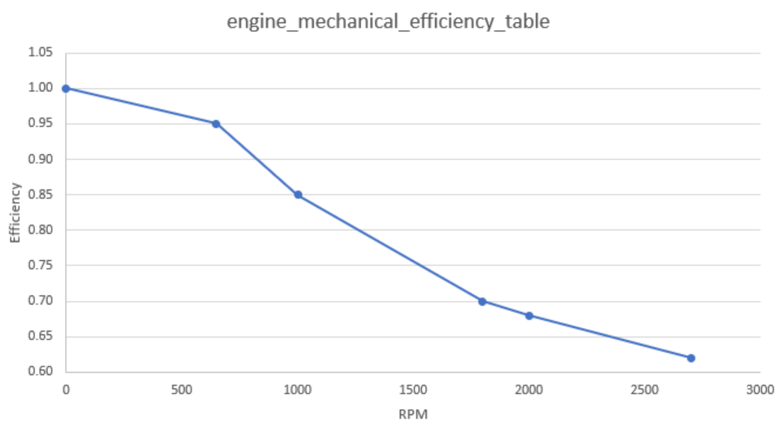
## engine.cfg

### [GENERALENGINEDATA]

- The position and basic properties of the engine have been set in this section.

### [PISTON_ENGINE]

- Most parameters have been determined from the flight manuals and data from the internet
- The average fuel consumption is 280 l/h
- The maximum flying range of the plane is 1600 km at cruise speed
- The parameters required tuning are the following:
    - power_scalar = 1
    - engine_mechanical_efficiency_table = 0:0.56, 500:0.79, 700:0.75, 1000:0.74, 1500:0.57, 2500:0.53, 2700:0.4859
    -




*RPM vs engine mechanical efficiency table values*

- idle_rpm_mechanical_efficiency_scalar = 1
- max_rpm_friction_scalar = 1
- BestPowerSpecificFuelConsumption = 0.47 ; For setting up the correct fuel flow

The engine mechanical efficiency table is used to tune power values at the pre-defined RPM values.

The engine performance is set to match values described in the Adjustments prior to test flights section.

Idle and maximum RPM have been tuned by using the engine mechanical efficiency, friction tables and the propeller settings.

### [PROPELLER]

- The main principles in propeller setup were the max static power-rpm relation and the correct vertical speed during climb
- The diameter of the propeller is 13.08 feet
- During prop modelling, the following parameters have been tuned:
    - prop_mod_lift_slope_cf = 3.35
    - prop_mod_lift_efficiency_cf = 0.2
    - prop_mod_zero_lift_drag_cf = 0.0145
    - power_propeller_absorbed_cf = 0.3; Coefficient of friction for power absorbed by propeller

## systems.cfg

### [BRAKES]

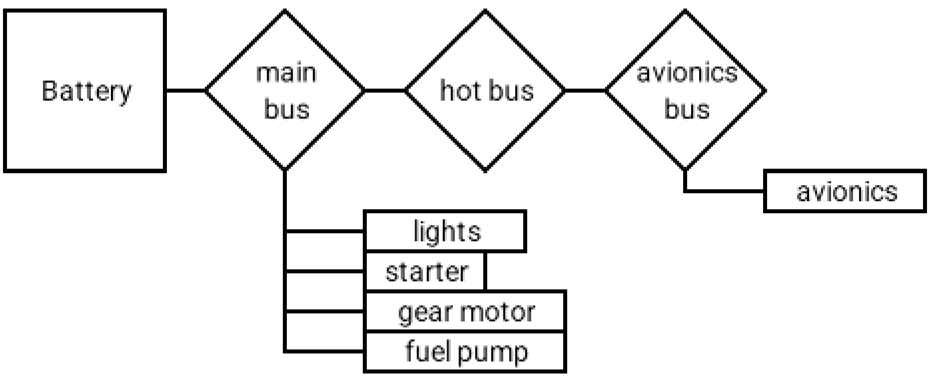
- No autobrakes
- The aircraft has a parking brake but depressing the pedals alone will not cause the parking brake to disengage.

### [LIGHTS]

- All lights according to the Flight Manual have been defined (navigation, taxi, landing, strobe, beacon, cabin, and panel) except for warning and signal lights.
- The position and rotation of the lights are defined in the Aircraft Editor.

### [ELECTRICAL]

The architecture of the electrical system used in the simulator is the following:




*Electrical system MSFS model*

The electrical system has been modelled according to the information found on the internet and the flight manual. All circuits have been modelled and tied to the appropriate electrical bus.

Power consumption values have been estimated and the total power consumption (if each component uses optimum power) should be slightly less than the total power supply of the generator.

**Procedures** are required for auto-start and auto-shutdown. These have been defined in the configuration file.

### [PITOT_STATIC]

Available

### [RADIOS]

- 2 communication system
- 2 navigation system
- ADF system
- Transponder
- Marker system

### [AUTOPILOT]

This airplane is equipped with a Model G1 automatic pilot.

# Adjustments prior to test flights

## Engine and prop

The engine power and the prop have been tuned to match the required power in the test case settings. Two characteristic points have been determined:

- Cruise power at 18000 lb, 6000’: 1600 RPM: 700 **bhp**
- Static engine power on the ground, sea level, 2650 RPM: **1660 bhp**

Engine and prop values will play a significant role in the climb and cruise performance, too. All other parameters are either set by using data from the flight manual or using the default values in the Microsoft Flight Simulator SDK documentation.

Before tweaking the flight model, the engine and prop characteristics (essentially the powerplant power) have been set at the selected characteristic points.

## Flight model

The flight model pre-adjustments start with setting the correct angle of attack vs lift curves. This determines that the aircraft will use the correct pitch at level flight, either in cruise conditions or in the wheelbarrow manoeuvre.

Stability parameters are not tuned, the modern flight model seems to do the job well.

# Test cases

An automated virtual flight testing of the aircraft is intended to showcase the flight characteristics of the model in a reproduceable way. The values might not be following factory behaviour perfectly but give an idea of the basic handling and show potential improvement areas. Developers of the actual flight model intend to match existing flight data as closely as possible, but no acceptance criteria will be based on the results found in this section.

All test cases assume a MTOW of 18000 lb. The tables below represent the test case scenarios with input and output conditions. Input conditions are for example altitude, power setting, configuration, and environment settings. Output can be any desired performance metric of the aircraft.

The Propair flight test software is used to fly the test cases and the results for each are plotted and calculated in the cloud. The flight test software flies the aircraft according to the input conditions of each test case and the next phase is activated only if the input and output variables have been stabilized. In case of dynamic tests, only the initial conditions must be stable, the dynamic test period is specified for each test.

The output parameters are not known in advance; thus, their change must remain within a specified range in the evaluation period (for “static” test cases). If the input or output parameters cannot be brought into the specified tolerance zone, the test case is skipped after 300 s (5 minutes).

### Take-Off

#### Definition

This scenario is testing the speed, power, and pitch parameters of the aircraft at a given configuration. Parameters are the following:

| | Input | Output | |
|---|---|---|---|
| **Name** | **Weight [lbs]** | **Take off roll [ft]** | **Take-Off Distance [ft]** |
| **0.1 Take off** | 18000 (MTOW) | 770* | 1600* |

*From POH

## Climb

### Definition

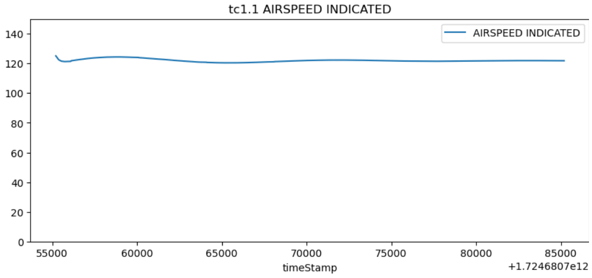
This scenario is testing the climbing performance with following parameters:

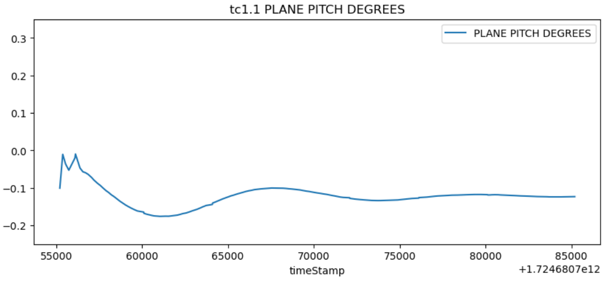
- Input parameters: RPM (±30)
  BHP
  IAS (±2 kts)
- Output variables: V/S (20 ft/min tolerance)
  Pitch (1˚ tolerance)

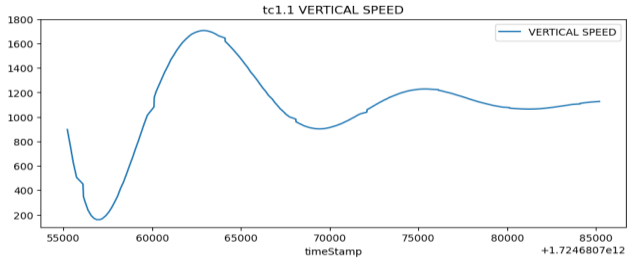
| | Input | | | | | Output |
|---|---|---|---|---|---|---|
| **Name** | **RPM** | **MP [inHg]** | **Altitude [ft]** | **Weight [lbs]** | **IAS [kt]** | **V/S [ft/min]** |
| **1.1 ClimbSL** | 2600 | 43 | Sea level | 18000 | 122 | 1250 |
| **1.2 Climb** | 2600 | 43 | 6000 | 16500 | 118 | 1350 |

## Results:

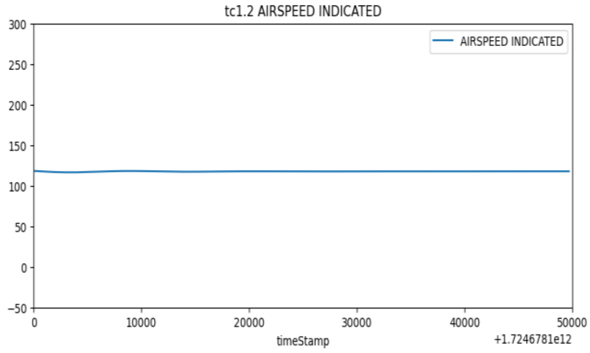
tc1.1 (20, 232) static | sealevelclimbvy
AIRSPEED INDICATED [121.73005348] min/max: [121.486771] / [121.949165]
PLANE PITCH DEGREES [-0.12175992] min/max: [-0.129802] / [-0.117626]
VERTICAL SPEED [1119.79200358] min/max: [1064.421158] / [1228.61652]

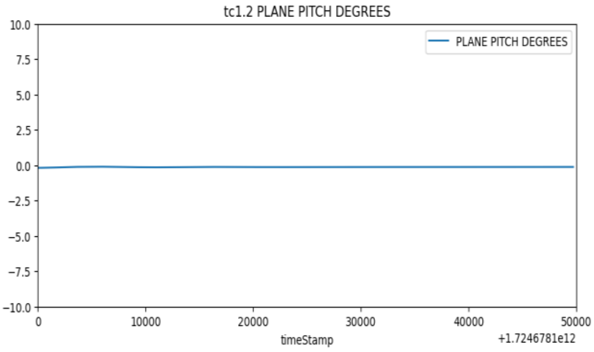


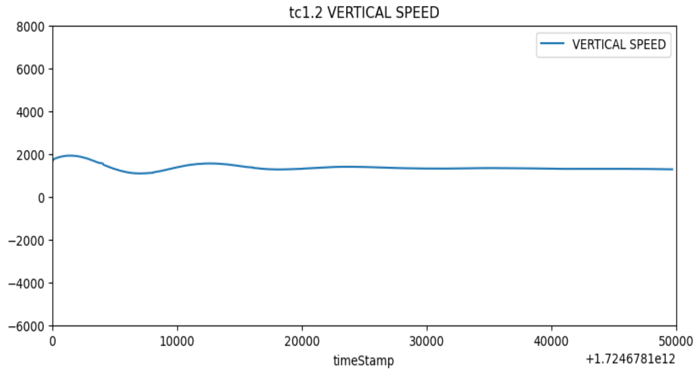




tc1.2 (5, 459) static | climbvy
AIRSPEED INDICATED [117.69186278] min/max: [117.654289] / [117.716553]
PLANE PITCH DEGREES [-0.1260368] min/max: [-0.127717] / [-0.123614]
VERTICAL SPEED [1298.35846327] min/max: [1278.27725] / [1306.22658]


tc1.2 AIRSPEED INDICATED
AIRSPEED INDICATED
timeStamp
+1.7246781e12


tc1.2 PLANE PITCH DEGREES
PLANE PITCH DEGREES
timeStamp
+1.7246781e12


tc1.2 VERTICAL SPEED
VERTICAL SPEED
timeStamp
+1.7246781e12

# Cruise

## Definition

This scenario is testing the speed, power, and pitch parameters of the aircraft at a given configuration.

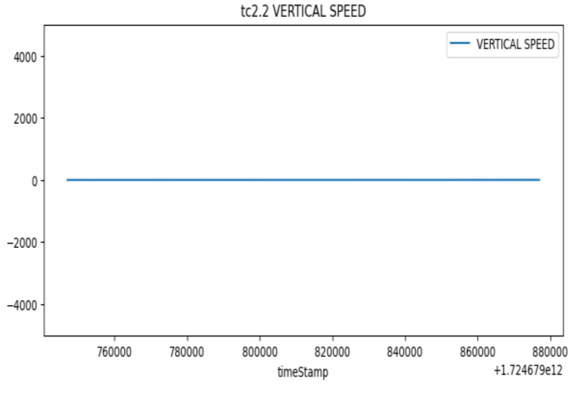
Parameters are the following:

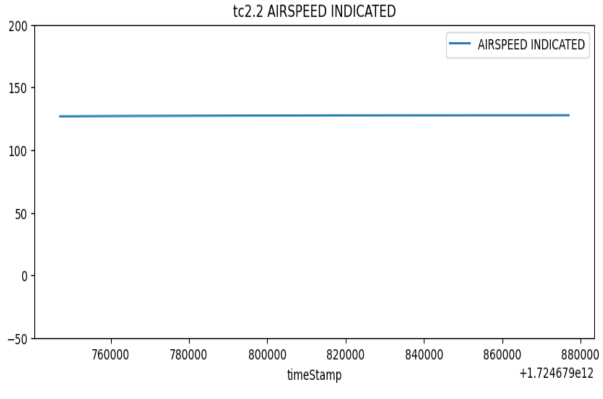
- Input parameters: RPM (±30)
  MP (±0.1)
  Altitude (±50 ft)
  BHP
- Output variables: IAS (1 kts tolerance)
  FF (±2 lb/h)

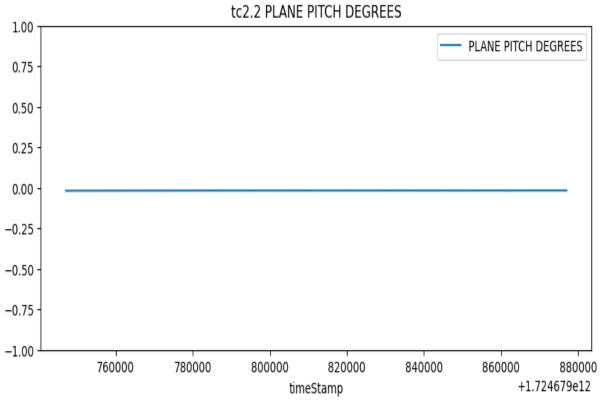
| | Input | | | | Output | |
|---|---|---|---|---|---|---|
| **Name** | **RPM** | **Altitude [ft]** | **MP [inHg]** | **Weight [lbs]** | **FF [lb/h]** | **IAS [kt]** |
| **2.2 Cruise** | 1600 | 8000 | 25 | 16000 | 600 | 125 |
| **2.3 Cruise** | 1600 | 6000 | 29 | 18000 | 600 | 135 |

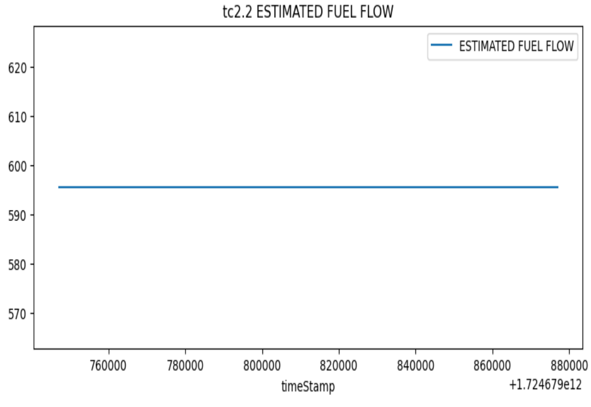
# Results:

tc2.2 (20, 1924) static | cruise65
AIRSPEED INDICATED [127.69998258] min/max: [127.684464] / [127.714607]
PLANE PITCH DEGREES [-0.0164056] min/max: [-0.016651] / [-0.016293]
VERTICAL SPEED [0.74775097] min/max: [0.54411] / [0.973268]
ESTIMATED FUEL FLOW [595.595] min/max: [595.595] / [595.595]



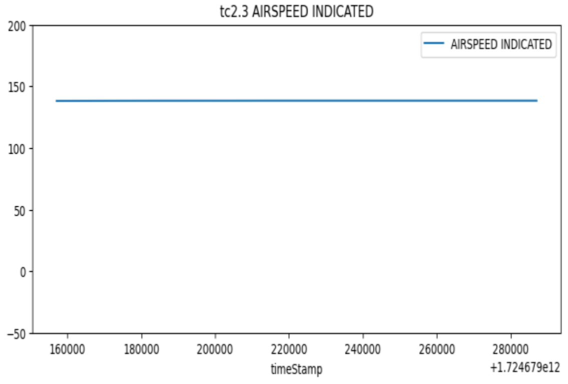
tc2.3 (9, 1932) static | cruise65

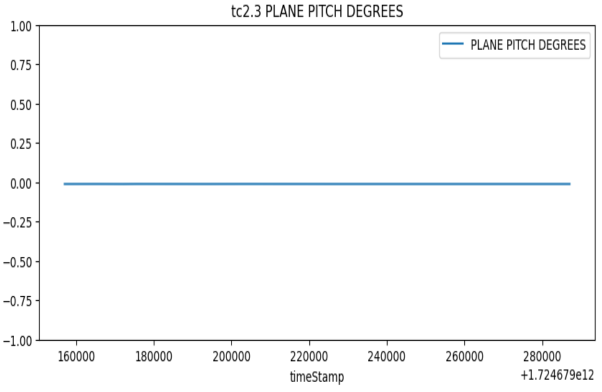
AIRSPEED INDICATED [138.34145466] min/max: [138.320923] / [138.355911]

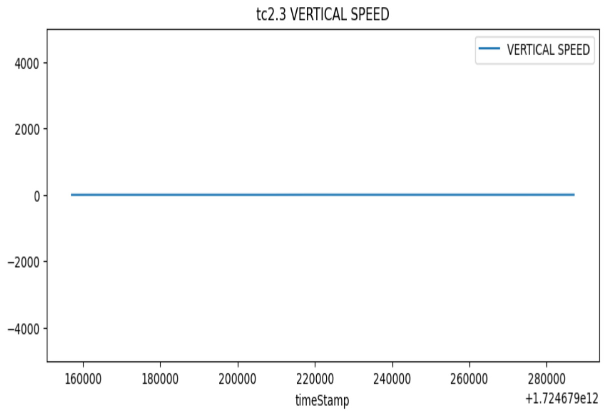
PLANE PITCH DEGREES [-0.01110164] min/max: [-0.011412] / [-0.010882]

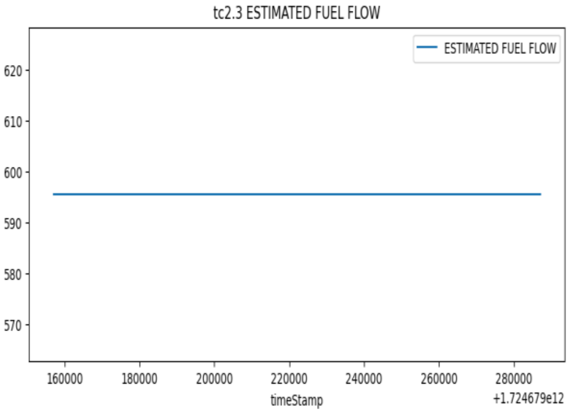
VERTICAL SPEED [0.86918192] min/max: [0.20475] / [1.554971]

ESTIMATED FUEL FLOW [595.595] min/max: [595.595] / [595.595]



# Stall

## Definition

Conditions: From economy cruise, power is set to idle, and the aircraft slows down to stall speed and below. IAS specified speeds apply for all altitudes.

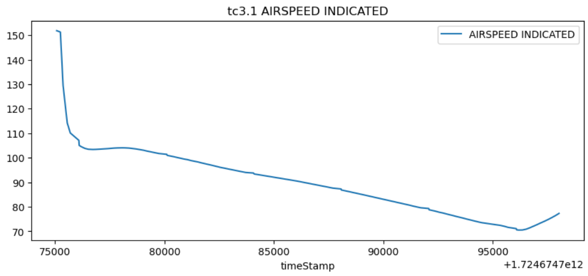
- Input parameters: Prop setting full forward
  Throttle minimum
- Output variables: no output variable to stabilize

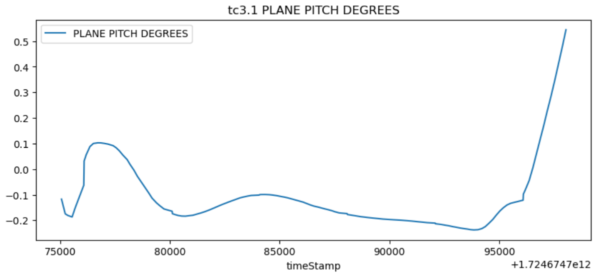
| | Input | | | Output | |
|---|---|---|---|---|---|
| **Name** | **Weight [lbs]** | **MP [inHg]** | **Altitude [ft]** | **IAS [kt]** | **Configuration** |
| **3.1 Stall** | 18000 | idle | 4000 | 72 | clean |

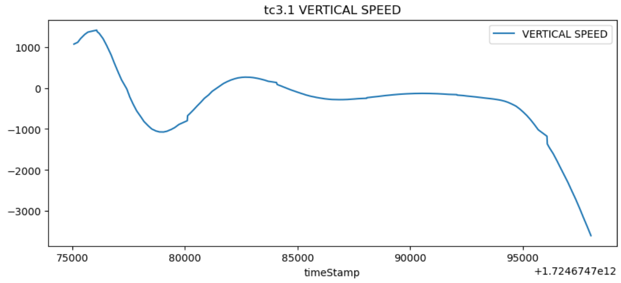
# Results:

tc3.1 (18, 181) stall | stall

AIRSPEED INDICATED [77.93122847] min/max: [70.504799] / [87.281822]
PLANE PITCH DEGREES [-0.11689026] min/max: [-0.237328] / [0.544307]
VERTICAL SPEED [-728.62854505] min/max: [-3597.29507] / [-131.615167]



# Glide

## Definition

This scenario is testing the glide performance with parameters following:

- Input parameters: Throttle IDLE
  RPM lowest
  IAS (±2 kts)
- Output variables: V/S (±20 ft/min)
  Pitch (1˚ bandwidth)

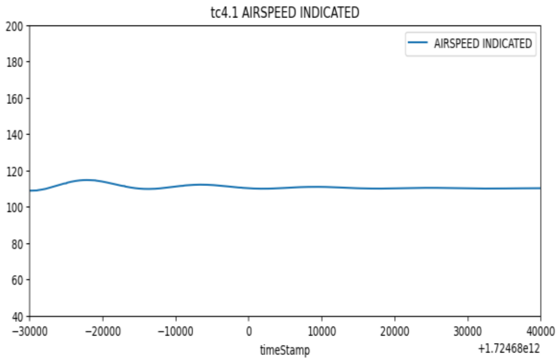
| | | | | | **Output** |
|---|---|---|---|---|---|
| **Name** | **Altitude [ft]** | **RPM** | **MP [inHg]** | **IAS [kt]** | **V/S [ft/min]** |
| **4.1 Glide** | 5000 | 1500 | idle | 110 | -1100* |

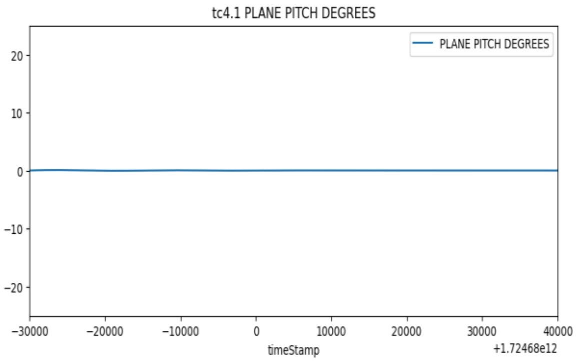
* Based on the glide ratio of 1:10, the vertical speed has to be -1100 ft/min.

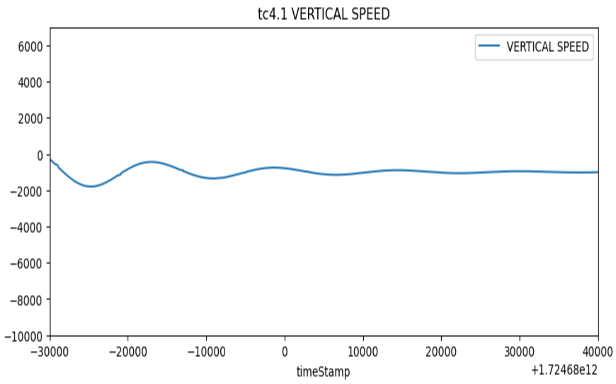
## Results:

tc4.1 (9, 519) static | glide

AIRSPEED INDICATED [110.0854501] min/max: [109.995453] / [110.195297]
PLANE PITCH DEGREES [0.02536161] min/max: [0.022374] / [0.02711]
VERTICAL SPEED [-995.53899956] min/max: [-1017.514343] / [-951.18124]




# Landing

| | **Input** | | | **Output** | |
|---|---|---|---|---|---|
| **Name** | **MP [inHg]** | **Altitude [ft]** | **IAS [kt]** | **Ground roll [ft]** | **Landing distance [ft]** |
| **5.1 Landing** | idle | Sea level | 80 | 900* | 1500* |

*From POH

# Operation manual

## Gear control

The Avenger has retractable gears, controlled with the *landing gear lever*, placed at the bottom left part of the front panel. The parking *brake* can be activated by the *parking brake* lever, which is on the left side of the gear lever.


*Landing gear lever (middle), Parking brake lever (left)*

The tailwheel can be locked, by setting the *tailwheel lock* lever, located on the left hand side of the pilot.


*Tailwheel lock*

Three indicators relating to each gear position can be found on the front panel. The light turns bright green, when gears are in the extended position.


*Gear indicators*

## Trim control

The Avenger has trim surfaces on all three primary control surfaces, aileron, rudder, and elevator. The trim controllers can be found on the lefthand side of the pilot.

*Trim controls*

The *biggest wheel* on the side of the box is related to *pitch trim*, the *wheel on the top* is the *rudder trim* controller, and finally the one, located *on the front* of the box is the *aileron trim* controller.

## Power control

The power controllers are also located on the left hand side of the pilot. The three main levers are shown in the picture below.

*From left to right: Propeller lever, Throttle lever, Mixture lever*

## Flap control

The Avenger has a flap system with four positions (retracted and 15°/30°/45°). It can be controlled by the lever, located on the right side of the landing gear lever.

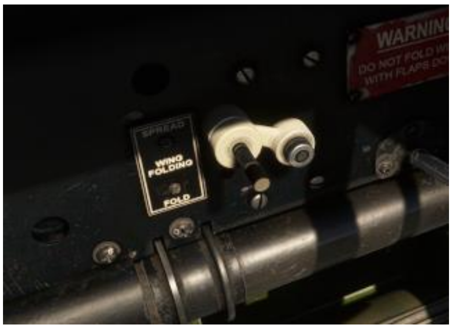
Flaps handle (right)

On the right hand side of the lever, an indicator can be found, which gives feedback about the current flap position.

Flaps position indicator

## Wing folding

The Avenger has a foldable wing system, which can be completely controlled from the cockpit. To spread the wings set the *wing fold switch* to position *spread*.



*Wing fold switch*

To make the aircraft ready for flight, please make sure that, the wings are locked with the *wing fold lock* lever. Please note locking the wings is possible only when the wings are fully opened.

*Wing fold lock*

To fold the wing, firstly the *wing fold lock* lever must be *pulled out* and then the *wing fold switch* must be set to *fold.*

**Engine startup**

Before starting the engine, please make sure that the parking brake is toggled and there is enough fuel for the mission. To start the engine, the following controls must be adjusted:

- Master switch: On


*Master switch*

- Generator: On (Switch located on the right panel)

*Right panel*

- Propeller lever: Low

- Fuel selector: Select the desired fueltank

*Fuel selector*

- Mixture: 100%

- Magneto switch: Both


*Magneto switch*

- Throttle: Approx. 10-15%
- Energizer: On (Located on the right panel)
- Once the engine is started, please turn off the energizer.