Aircraft Design Toolbox for Scilab

Abstract

Modern aircraft are a complex combination of aerodynamic performance, lightweight durable structures, efficient engine, precise control system and **advanced systems engineering.**

In order to design an aircraft numerous disciplines have to be blended together to yield the optimum configuration to meet a given requirement. This is inevitably an iterative procedure which consists of alternative phases of design and analysis. Many compromises are inevitable. This calls for a software tool to facilitate engineers to effectively manage and keep track of these trade-offs.

Aircraft Design Toolbox for Scilab is a library to create **conceptual aircraft design** using Scilab. It follows a top-to-bottom design philosophy. Starting from requirement capturing and ending with performance analysis. It includes following modules:

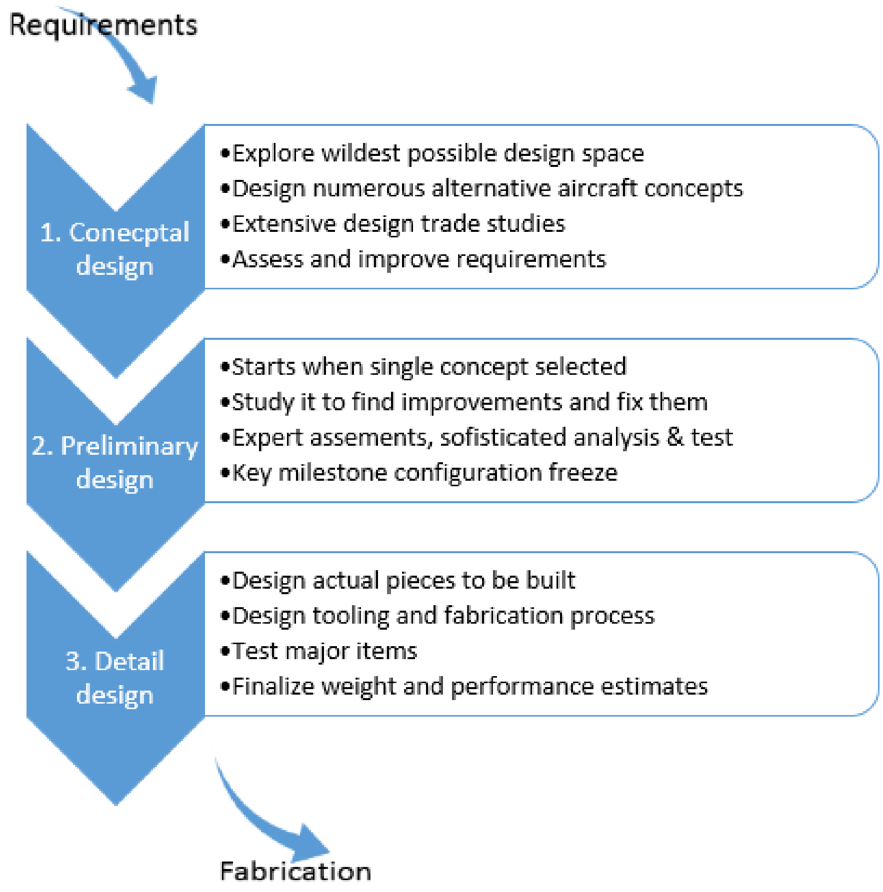
1. Requirement: captures top level requirements of an aircraft
2. Weight estimation: measures initial gross weight using historical trends
3. Mission: captures aircraft mission profile
4. Initial sizing: finds out dimension of the aircraft component
5. Drag : finds out total drag due to all the components
6. Performance analysis: finds out performance to be compared against requirements

Technical aspects of the proposal

Problem

Technical solution

Aircraft design process includes 3 major phases:

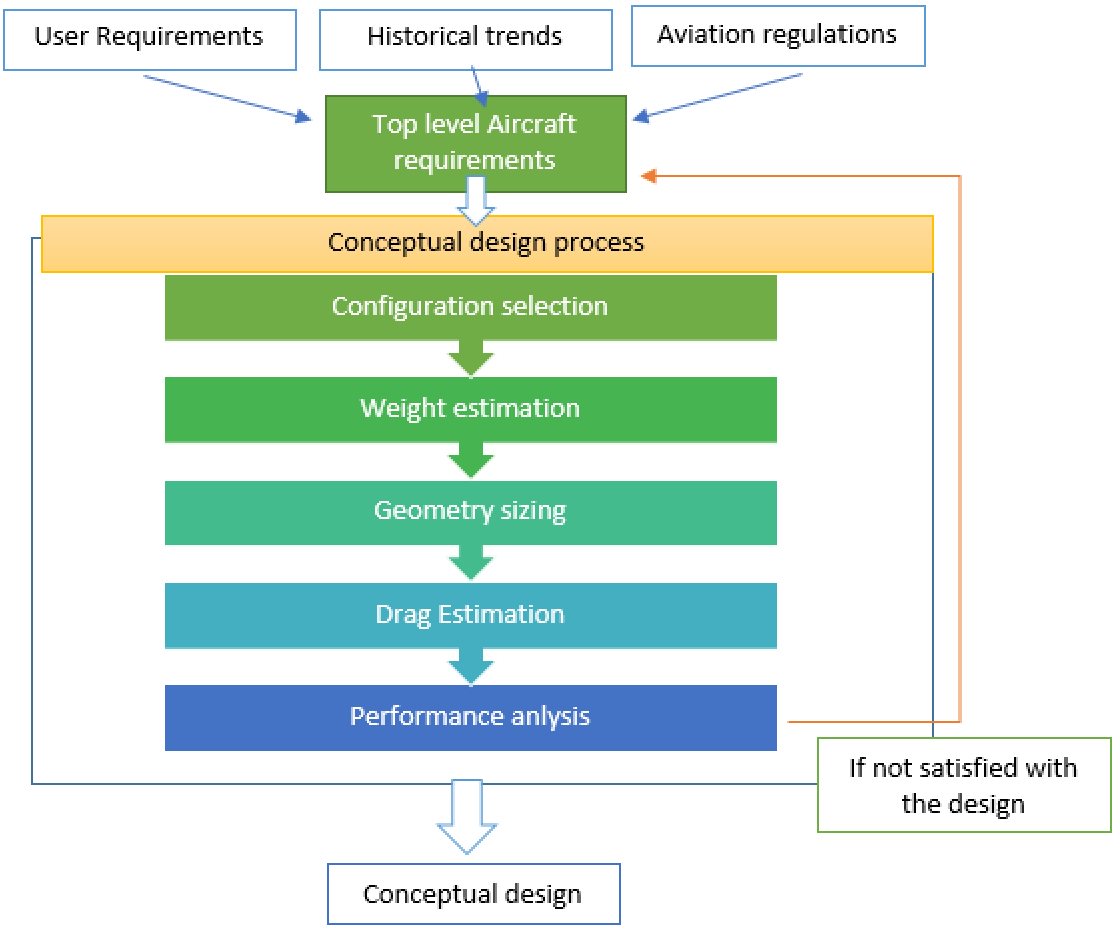


Conceptual design is the first and most important phase of the aircraft system design and development process. It is an early and high level life cycle activity with potential to establish, commit, and otherwise predetermine the function, form, cost, and development schedule of the desired aircraft system.

In Conceptual Design, the basic questions of configuration arrangement, size, weight, and performance are answered. Numerous alternative design concepts are prepared in response to the design requirements, and numerous variations on those concepts are also studied. In conceptual design, the design requirements are used to guide and evaluate the development of the overall aircraft configuration arrangement.

Aircraft Design Toolbox for Scilab will focus on building a workflow for Conceptual design only. The procedure detailed by *Daniel P. Raymer* in the book "Aircraft Design: A Conceptual Approach" will be followed throughout.

Conceptual design process



Top level requirements

These requirements are to be provided before the design process starts

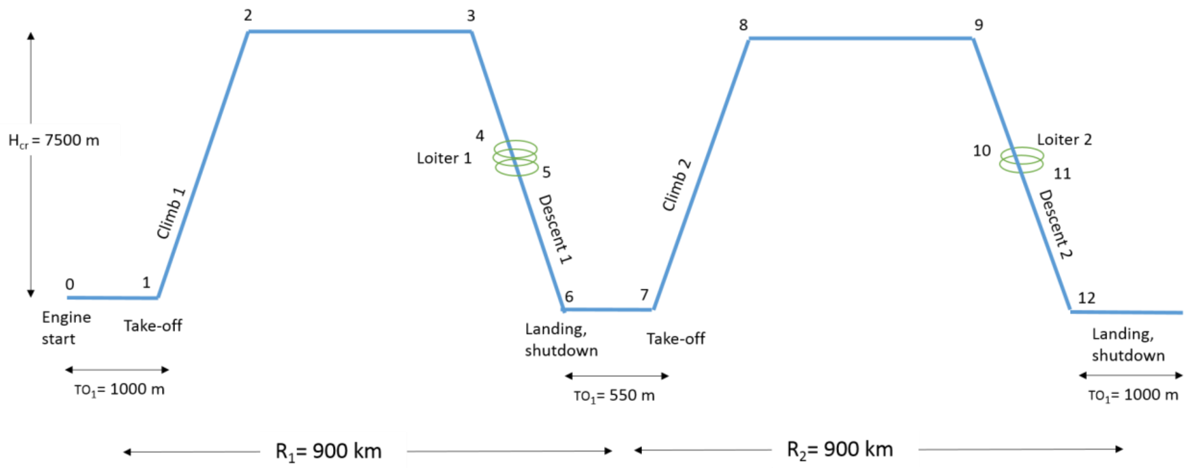
- Max. Take-off Distance
- Landing Distance
- Range
- Crew
- Payload
- Cruise Velocity
- Stall Speed
- Rate of Climb
- Service Ceiling
- Mission profile

For this toolbox **Aircraft Class** type will be also asked from the user. Historical trends will be used to determine various parameters for each class. A list of aircraft class is presented here

- Flying Boat
- Sailplane (unpowered)
- Sailplane (powered)
- Homebuilt-metal/wood
- Home-built composite
- General Aviation-1 Engine
- General Aviation-2 Engine
- Agricultural aircraft
- Twin turboprop
- Jet trainer
- Jet fighter
- Military cargo
- Jet transport

Mission profile

Any aircraft is designed for a particular mission. Mission profile depicts mission requirements in terms of range and altitude. It will be used to find Fuel weight fraction. An example of mission profile looks as following.



Initial assumptions

The first iteration of the design requires certain assumptions for various aircraft parameters based on historical data and existing aircraft in the market.

Configuration Selection

The user has to select among the following aircraft component configuration

Wing Configuration	Number of wings	• Monoplane • Biplane • Triplane
	Wing location	• High wing • Mid wing • Low wing • Parasol wing
	Wing type	• Rectangular • Tapered • Delta • Swept back • Swept forward • Elliptical
	High lift device	• Plain flap • Split flap • Slotted flap • Kruger flap • Double slotted flap • Triple slotted flap • Leading edge flap • Leading edge slot
	Sweep configuration	• Fixed wing • Variable sweep
	Shape	• Fixed shape • Morphing wing
Tail Configuration	Aft or forward	• Aft conventional tail • Canard (fore plane) • Three surfaces
	Horizontal and vertical tail	• Conventional • V-tail • T-tail • H-tail • Inverted U
	Attachment	• Fixed tail • Moving tail • Adjustable tail
Propulsion Systems	Engine type	• Human powered • Solar powered • Piston prop • Turboprop • Turbofan • Turbojet • Rocket
	Engine and the aircraft centre of gravity	• Pusher • Tractor

	Number of engines	• Single-engine • Twin-engine • Tri-engine • Four engine • Multi-engine
	Engine location	• In front of nose (inside) • Inside fuselage mid-section • Inside wing • Top of the wing • Under wing • Inside vertical tail • Side of fuselage at aft section • Top of the fuselage
Landing Gear Configuration	Landing gear mechanism	• Fixed (a. faired, b. un-faired) • Retractable • Partially retractable •
	Landing gear type	• Tricycle (or nose gear) • Tail gear (tail dragger or skid) • Bicycle (tandem) • Multi-wheel • Bicycle (side-by-side) • Float-equipped • Removable landing gear
Runway		• Land-based • Sea-based • Amphibian • Ship-based • Shoulder-based (for small remote controlled aircraft) •
Fuselage Configuration	Door	• Cabin • Cockpit
	Seat	• Tandem • Side-by-side • n-seats per row •
	Pressure system	• Pressurized cabin • Pressurized hose • Unpressurized cabin

Gross weight estimation

Based on historical data and the requirements specified an initial gross aircraft weight is determined. The procedure detailed by Daniel P. Raymer in the book "Aircraft Design: A Conceptual Approach" will be followed for this

$$W_0 = \frac{W_{crew} + W_{pay}}{1 - \{\widehat{w}_e + \widehat{w}_f\}}$$

The weight of the crew (W_{crew}) and the payload weight (W_{pay}) are available from the top-level aircraft requirements. The empty weight fraction ($\widehat{w}_e$) is estimated from the historical data available. The fuel weight fraction is estimated using the **Breguet range equation** for the cruise phases and **endurance**

equation for the loiter segments. The take-off, climb, descent and landing segment weight fractions are estimated from historical.

Breguet range equation:

$$R = \frac{V_{cruise}}{c_{cruise}} \cdot \left[\frac{L}{D}\right]_{cruise} \cdot \ln\left\{\frac{W_{i-1}}{W_i}\right\}$$

Endurance equation

$$E = \frac{1}{c_{loiter}} \cdot \left[\frac{L}{D}\right]_{loiter} \cdot \ln\left\{\frac{W_{i-1}}{W_i}\right\}$$

Geometry Sizing

Constraint analysis

The constraint analysis estimate the ideal **wing-loading** and **thrust loading** which satisfies a set of landing, take-off, climb rate, stall speed and climb gradient constraints.

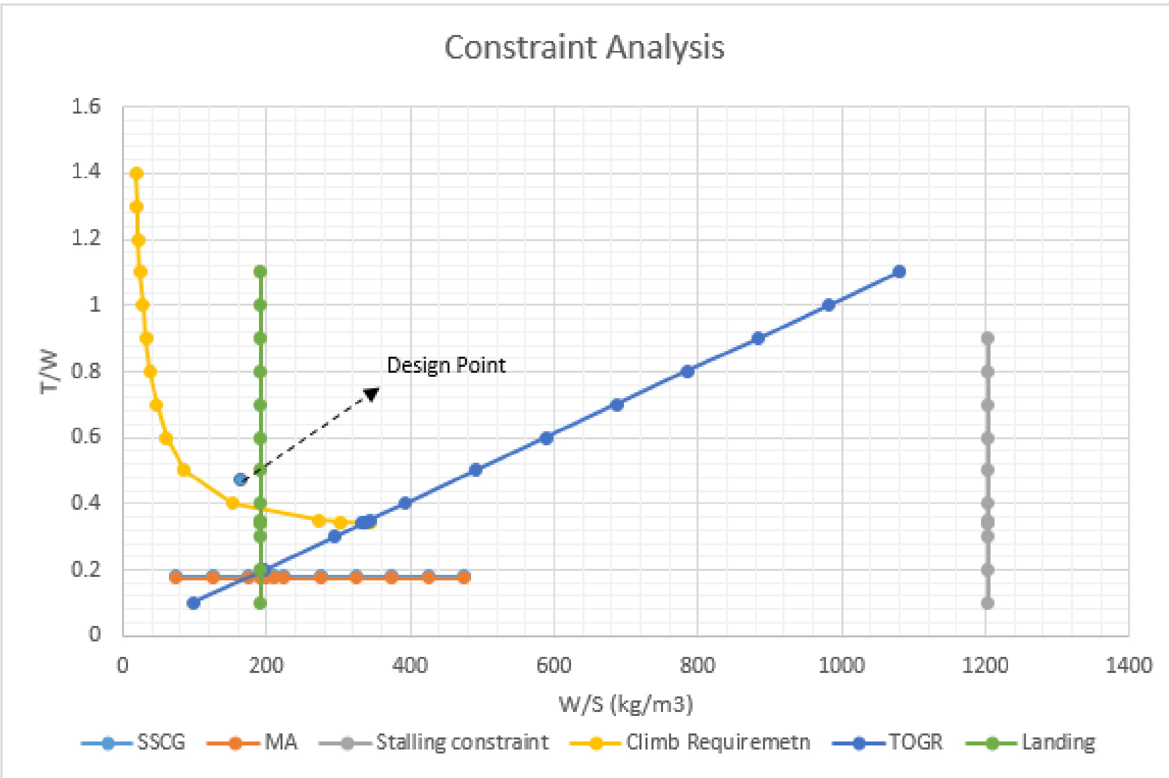


Figure showing constraint analysis

Fuselage sizing

Fuselage sizing is dependent on the sizing of the cabin based on the passengers, crew and amenities. For now this toolbox will be expecting fuselage dimension to be given by the user

Wing Sizing

Wing reference area can be determined from wing loading and the gross weight estimated.

$$Wing\ reference\ area\ (S_{ref}) = \frac{Gross\ weight}{Wing\ loading}$$

The dimensions of the wing can be determined for a wing of aspect ratio, taper ratio (λ) and sweep at max t/c (at 30% chord - $\wedge_{0.3}$) as:

$$Span\ (b) = \sqrt{A.R \times S_{ref}}$$

$$L.E\ Sweep\ (\wedge_0) = \tan^{-1}\left(\frac{4 \times 0.3}{A.R} \times \frac{1-\lambda}{1+\lambda}\right)$$

$$Root\ Chord\ (c_{root}) = \frac{2 \times S_{ref}}{1.5 \times b}$$

$$Tip\ chord\ \left(c_{tip}\right) = \lambda \times c_{root}$$

$$Mean\ chord\ (\bar{c}_w) = \frac{c_{root} + c_{tip}}{2}$$

Selecting an airfoil for the wing requirements is premature for the first design iteration. An approximate design lift coefficient for the airfoil can be determined from the level flight condition as:

$$C_l = \frac{1}{q}\left(\frac{W}{S}\right)_{cruise}$$

The cruise aircraft weight is assumed from historical trends of take-off and climb weight fractions

Tail sizing

The tail sizing is done based on a historical approach based on tail volume coefficients (C_{HT} and C_{VT}). The horizontal tail arm length (L_{HT}) is a decisive factor in sizing the tail. For the first iteration, the wing quarter chord is assumed to be located at the centre of the cabin and tail quarter chord to be located at the aft end of the fuselage. The vertical tail arm length (L_{VT}) is assumed to be equal to horizontal tail arm length.

$$L_{HT} = \frac{Cabin\ Length}{2} + Tail\ length$$

The plan form areas for the horizontal and vertical tail ($S_{HT}$and S_{VT}) is calculated by

$$S_{HT} = \frac{C_{HT}\bar{c}_w S_w}{L_{HT}} \qquad\qquad S_{VT} = \frac{C_{VT} b_w S_w}{L_{VT}}$$

The values of the tail volume coefficients are taken from historical data.

Drag Estimation

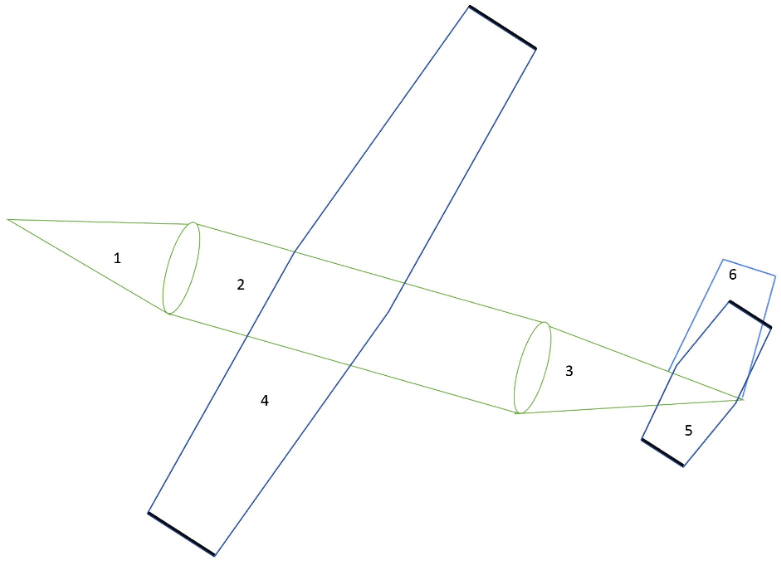
The dimensions from the initial geometry selection can give a very rough indicative value of the drag of the aircraft. From the historical trend for wetted area ratio, $C_{D,0}$ of aircraft will be obtained.

Equivalent skin friction method

The equivalent skin friction is obtained from historical trend. The drag coefficient can be estimated from wetted area ratio as follows:

$$C_{D,0} = C_{fe} \frac{S_{wet}}{S_{ref}}$$

To estimate S_{wet} for the aircraft, the aircraft layout is approximated into a simple geometry as following figure.



Simplified aircraft geometry

- Each major component of the aircraft is a simplified geometry as follows:
- h = height, w= width, l = length for 1, 2 and 3
- h = height and a, b are parallel sides for 4, 5, 6
- C.S.A = cross section area

1. Right-angled elliptical cone

$$C.S.A \approx \pi\left(\frac{h+w}{2}\right)\sqrt{l^2+\left(\frac{h+w}{4}\right)^2}$$

2. Elliptical cylinder

$$C.S.A \approx \pi\left(\frac{h+w}{2}\right)l$$

3. Oblique elliptical cone

$$C.S.A \approx \pi\left(\frac{h+w}{2}\right)\left(\frac{l+\sqrt{l^2+\left(\frac{h+w}{2}\right)^2}}{2}\right)$$

4, 5, 6. Trapeziums

$$S.A = \frac{1}{2}h(a+b)$$

For wing, H.T and V.T (surfaces 4, 5 & 6) the total wetted area is not equivalent to the exposed surface area obtained from the equation above. The wetted surface area is also dependent on thickness ratio ($\lambda_{t/c}$) as follows:

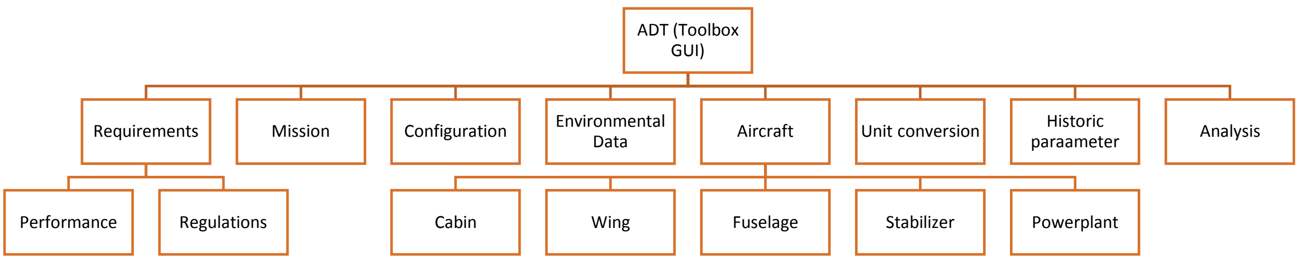
$$S_{wet} = S_{exp}(1.977 + 0.52\,\lambda_{t/c})$$

Thickness ratio for horizontal and vertical tail is estimated to be almost same as that of NACA 0012, as the tail airfoils usually come under this category.

Scilab implementation

The toolbox will be available as Scilab macros with both command line and GUI version

Structure of the modules will be as following



All aircraft data will be created with Scilab struct datatype.

The toolbox can be currently found here: https://github.com/ashishact/ADT

How the feature will be available to the user.

Command line version

Command line version if available by default, because of the open nature of Scilab.

GUI version

A GUI version will also be available which will build a workflow for the designer. It will provide a step by step procedure to carry out the entire design task

Schedule

According to GSoC-2015 timeline

- 27 April: Accepted student proposals announced on the Google
- 25 May: begin coding
- **26 June**: **midterm evaluation** begins
- 17 August: Test and documentation
- **21 August: final evaluation**
- 28 August: submit code

There are approximately **8 weeks before midterm** (27^{th} April to 26^{th} June) and **8 weeks after midterm** (26^{th} June to 21^{st} August). Here is a list of objective for each week.

Before GSoC begins:

- Look at already existing conceptual design toolbox like CEASIOM.
- Learn more about Scilab GUI modules

1^{st} week

- Write functions to capture requirements
    - Top level aircraft requirement definition
    - e.g. Cruise speed, rate of climb, range
- Aircraft Class definition and declare data associated with each class type
- Environment data definition
    - E.g. ISA constants, density of air, gamma value for air

2^{nd} week

- Aviation regulation data definition and functions (e.g. FAR 23)
- Historical data definition Environment data definition
- Functions for conversion between SI and Imperial units

3^{rd} week

- Configuration selection
    - Functions to select component (wing, fuselage, cabin, stabilizers, powerplant)
- Mission definition
    - functions for defining mission segments
    - functions for defining multiple missions

4th week

- Main Toolbox GUI design
- GUI for requirement capture
- GUI for configuration selection(wing, fuselage, cabin, stabilizers, powerplant)

5th week

- Initial sizing
    - Functions for Constraint analysis
    - GUI for Constraint analysis
- Gross weight estimation
    - Create Functions
    - create GUI
- Fuel fraction estimation
    - Create functions
    - Create GUI
- Documentation of work done till now

6th week

- Wing geometry sizing
    - create functions
    - create GUI
- Fuselage geometry sizing
    - create functions
    - create GUI

7th week

- V-Tail geometry sizing
    - create functions and GUI
- H-Tail geometry sizing
    - create functions and GUI
- Drag estimation (total Aircraft drag except landing gear)

8th week

- Performance analysis
    - Compute Lift and Drag
    - functions to find
        - Take-off field length
        - Landing field length
        - Climb performance
        - Cruise performance and range
        - service ceiling
        - Engine Power requirement
- Documentation for midterm evaluation

9^{th} week

- Create plots and GUI for performance analysis
- Compute mission performance
    - GUI for mission performance

10^{th} week

- Landing gear definition
- Add drag due to landing gear
    - GUI for adding landing gear parameter

11^{th} week

- Fuselage Design in a graphical window
    - Cabin design
    - compute outer dimension of fuselage from GUI
- Test and verify output against standard Aircraft data

12^{th} week

- Mission design in a graphics window
    - add/remove mission segment
    - create and edit multiple mission

13^{th} week

- Flap design
    - additional lift due to flap
- 2D visualisation for aircraft (top and front orthographic view)
- Functions for Saving/Loading design data in a XML file

14^{th} week

- Writing tests and demo
    - test weight estimation functions (this function is recursive. check for its convergence)
    - shows basic functionalities of the toolbox

15^{th} week

- Writing tests and demo
    - demo of designing an Aircraft from beginning(requirements) to end (performance analysis)

16^{th} week

- Write/Refine Documentation

Future work

The GSoC timeline is only enough to build a basic toolbox. In order to create full fledge toolbox few more modules will be required. So they have to be programmed after GSoC is over. A small list of those modules is listed here.

- 3D visualization of the designed aircraft in Scilab
- OpenVSP integration: OpenVSP is a parametric aircraft geometry tool, originally created by NASA. For more visit: http://openvsp.org/
- Aircraft stability and Control module

Personal Information

I am an Aerospace Engineering Undergraduate from Indian Institute of Technology, Bombay, India. Currently I am in my 4th year and I am 21 years old.

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IT languages I am familiar with

- C++: created a program to control a Mars Rover prototype designed by IITB Mars Rover Team for University Rover Challenge. Find it in GitHub: https://github.com/ashishact/URCUI
- Python: I use python for writing code for my courses
- Java: Used it especially for building GUIs. Created an OBJ 3d file importer using JavaFX.

Version control system I am familiar with

- GIT: https://github.com/ashishact

I use Scilab frequently for my courses. I have been part of Scilab textbook companion project organised by "Scilab India". As part of this I coded all the solved example of "*Elementary Fluid Mechanics by J. K. Vennard*" in Scilab. More details: http://www.scilab.in/textbook_run/2789

Plans after GSoC

Requirements of my module are such that I do have to continue after GSoC is over. I plan create few more modules. I will be the maintainer of this toolbox.

Formal commitment that I will be involved full time on the GSoC

I will be working 40 hours per week for GSoC. I do not have any other commitments during summer.

As required I have compiled Scilab and modified the default banner and posted the screenshot in the mailing list. I have also created a basic toolbox based on the skeleton provided by Scilab. It can be found in https://github.com/ashishact/ADT.