CRANFIELD UNIVERSITY

PAN JING

DEVELOPMENT OF GROUND STATION DISPLAY AND FLGIHT MANAGEMENT SYSTEM FOR LOW-COST VEHICLE

SCHOOL OF ENGINEERING

MSc by Research Thesis

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Supervisor: Dr. Huamin Jia

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ABSTRACT

Nowadays, with the development of electronic and communication technologies, more and more low-cost vehicles such as small, light-weight aircraft are widely applied in all kinds of fields. Ground Station is an essential part of low cost vehicles for the operator to control and monitor the vehicles.

In this thesis, Ground Station Display and Flight Management System for Low-Cost Vehicles have been developed.The major objective of this project is to design an intuitive and easy operative Human Machine Interface for displaying and monitoring the flight data and traffic information on ground. Meanwhile, a Graphic User Interface for the Flight Management System has been developed for realizing the waypoints input and flight plan for the vehicles.

To fulfill this task, a low-cost hardware and software architecture is presented. Moreover, some COTS tools such as VAPS and MATLAB are applied for the software development because of their Object-Oriented and Rapid Prototype design methods.

At the end of project, simulation has been done for the display HMI to test the behaviours of objects and the impacts of display. The trajectory simulation of flight management control panel is also implemented to test the waypoints creation, trajectory generation and smoothing.

Keywords:

COTS, GUI, HMI, Object-Oriented Design, Rapid Prototype, VAPS, MATLAB, simulation, waypoint, trajectory generation, trajectory smoothing

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ACRONYM

ADI	Attitude Director Indicator
ATN	Augmented Transition Network
AVIC	Aviation Industry Corporation of China
CCG	C Code Generation
CDS	Cockpit Display System
COTS	Commercial off-the-shelf
CRT	Cathode Ray Tube
EVS	Enhanced Vision Systems
FCS	Flight Control System
FF	Formation Flying
FHA	Function Hazard Analysis
FMS	Flight Management System
GDP	Group Design Project
GPS	Global Position System
GS	Ground Station
GSC	Ground Station Computer
GUIDE	Graphical User Interface Development Environment

GUIs	Graphic User Interfaces
HMI	Human Machine Interface
IE	Integration Editor
INS	Inertial Navigation System
IP	Internet Protocol
IRP	Individual Research Project
LCV	Low-Cost Vehicle
LRU	Line Replaceable Unit
ND	Navigation Display
OBC	Onboard Computer
OE	Object Editor
OpenGL	Open Graphics Library
PFD	Primary Flight Display
PP	Path Planning
PSSF	Preliminary System Safety Assessment
R/C	Radio Control
RE	Runtime Environment
SE	State-form Editor

SSA	System Safety Assessment
TG	Trajectory Generation
TS	Trajectory Smoothing
TT	Trajectory Track
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol

1 Introduction

1.1 GDP Work

The Flying Crane is a 130 seat civil aircraft which was completed as group design project (GDP) by the groups of AVIC students. The conceptual and preliminary design was finished in 2008 and 2009 by the first and second groups. The main results are showed in Flying Crane Preliminary Design Project Executive Summary [1] and other individual GDP reports. In 2010, the detailed design of Flying Crane was carried out as GDP by the third group students.

The author is responsible for Cockpit Display System and Enhanced Vision Systems. The design process is executed by these following steps:

The first step: the detailed design started with last two years' results of the conceptual and preliminary design. Therefore, the first of all work was to review and validate the results of previous design which includes: definitions and requirements analysis, system performance analysis, data collection, system architectures design, display layout design, FHA and PSSA analysis [2].

The second step: allocated requirements to hardware and software, then implemented the system according to the guidance of ARP (Aerospace Recommended Practice) 4754 [3]. In this phase, hardware decision and interface coordination were finished on the base of previous work result. During the design, DO254 was referred to the hardware design and DO178B was referred to software design process [4][5].

The third step: in this phase, software development of Primary Flight Display and Navigation Display design were performed under the direction of AC25-11 [6]. Finally, the basic Primary Flight Display and Navigation Display simulation software was developed.

The fourth step: to integrate the software simulation result with other avionics subsystem such as Communication System and Flight Management System (FMS) via UDP/IP protocol.

In addition, some of System Safety Assessment jobs have been performed for the display system according to the guidance of ARP 4761 [7].

Another target of GDP was the design of Enhanced Vision System for Flying Crane. The EVS design began with the requirements analysis, then the system architecture and hardware design had been done. Finally, the FHA for EVS was given out.

The whole work in the GDP is presented by Appendix A, Appendix B and Appendix C.

1.2 Background of Individual Research Project

In recent years, more and more low-cost vehicles have been developed and applied. These vehicles have been opening a new market in the aeronautics field. Most of low-cost vehicles (LCS) such as small, light-weight ones are primarily developed in the universities and laboratories for acquiring all kinds of information instead of human collection. These low-cost vehicles are widely applied in all kinds of civil fields, for example: they are able to fulfil a number of civilian roles, carrying out surveillance and monitoring tasks. Such tasks include border patrol for drug smuggling or illegal immigrates, coast guard patrol, inspecting electrical power lines, monitoring gas or oil pipe lines, forest and agricultural/environmental monitoring, traffic monitoring and urban surveillance. They have also been used for crop spraying in some countries.

Ground Station is a crucial element of low-cost vehicles to allow the operator to control and monitor the remote aircraft. The development of ground station becomes more and more important because good ground station can reduce operator workload and improve mission performance.

1.3 Aim and Objective of Individual Research Project

The aim of Individual Research Project is the Development of Ground Station Display and Flight Management System for Low-Cost Vehicle. This project mainly includes two aspects:

1. One aspect is the intuitive, easy-to-use Human-Machine Interfaces development. The major display contents include:

   - Flight data display
   - Aircraft attitude data display
   - Navigation data display
   - Status monitor data display

2. The other aspect is the design of Flight Management System (FMS) on how to implement the flight path planning on the ground for guiding the vehicle flying in the air. The major context should be researched in Flight Management System includes:

   - Waypoints Creation
   - Trajectory Generation
   - Trajectory Smoothing

At the end of the Individual Research Project, some simulations and Implements for display and path planning on the ground station should be presented.

1.4 Research Plan

The following work should be accomplished within five months:

1. September of 2010: literature review;
2. October of 2010: the layout and display design of ground station for low-

cost vehicle;

3. November of 2010: interface issue and data & information analysis downlink from the vehicle;
4. December of 2010: flight path planning design of ground station and system simulation;
5. January of 2011: system simulation and thesis write-up.

The main task and schedule of project is shown in Table 1-1.

Table 1-1 Main Task and Schedule of IRP

	Sep.	Oct.	Nov.	Dec.	Jan.
Literature Review	■				
System Architecture Design	■	■			
Display System Design	■	■			
Interface Design		■	■		
Flight Path Planning Design		■	■	■	
System Simulation and test				■	■
Thesis writing	■	■	■	■	■

2 Literature Review

2.1 System Architecture

Several UAV system architectures have been suggested in the past. One of typical system architectures is given out by Brigham Young University in Figure 2-1 [8].

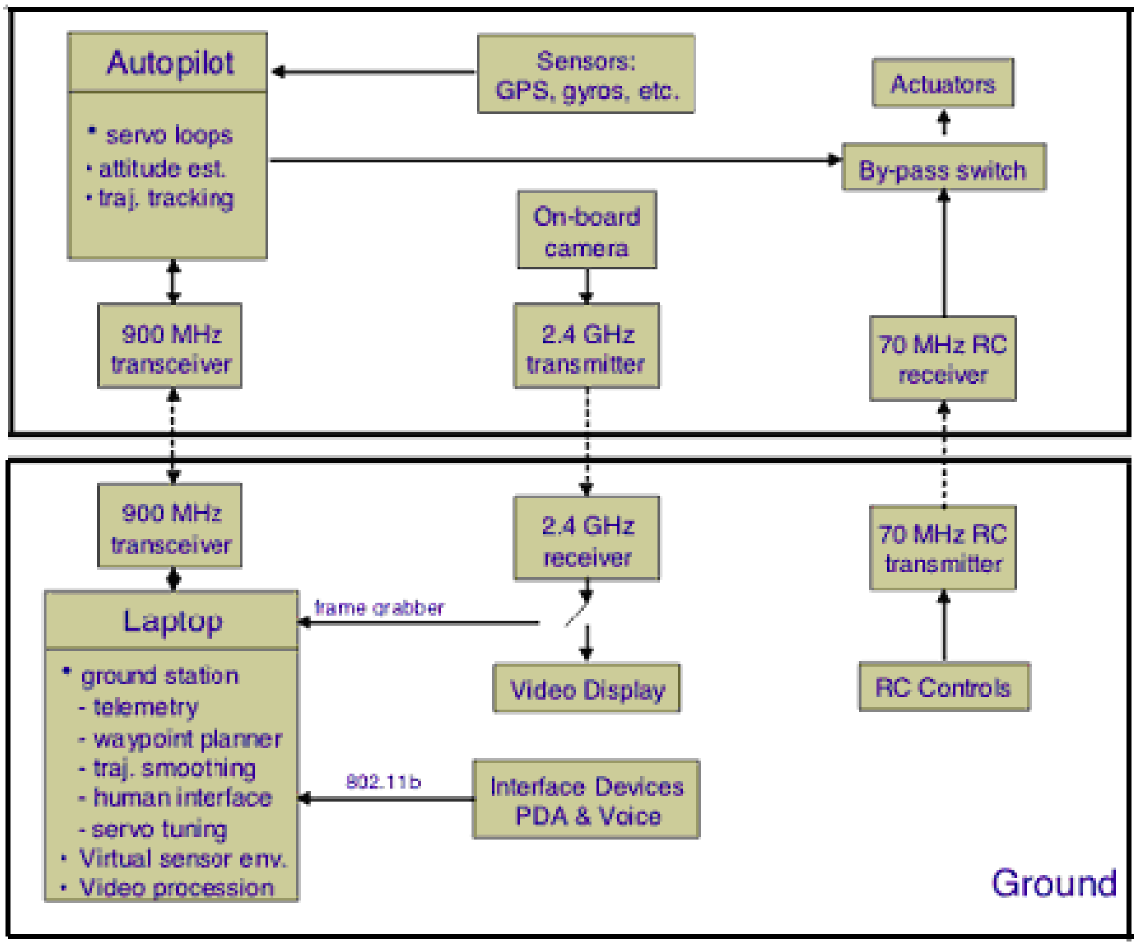


Figure 2-1 System Architecture [8]

From this architecture, it can be found that the Ground Station is a critical component for Low-Cost Vehicle. It is responsible for performing the data process and link between the onboard system and ground control.The main functions of ground station in this system architecture are telemetry, waypoint planner, trajectory smoothing, Human Machine Interface and servo tuning.

Another typical architecture for low-cost vehicle is also given out by the paper of Hsiao [9] which is shown in Figure 2-2.

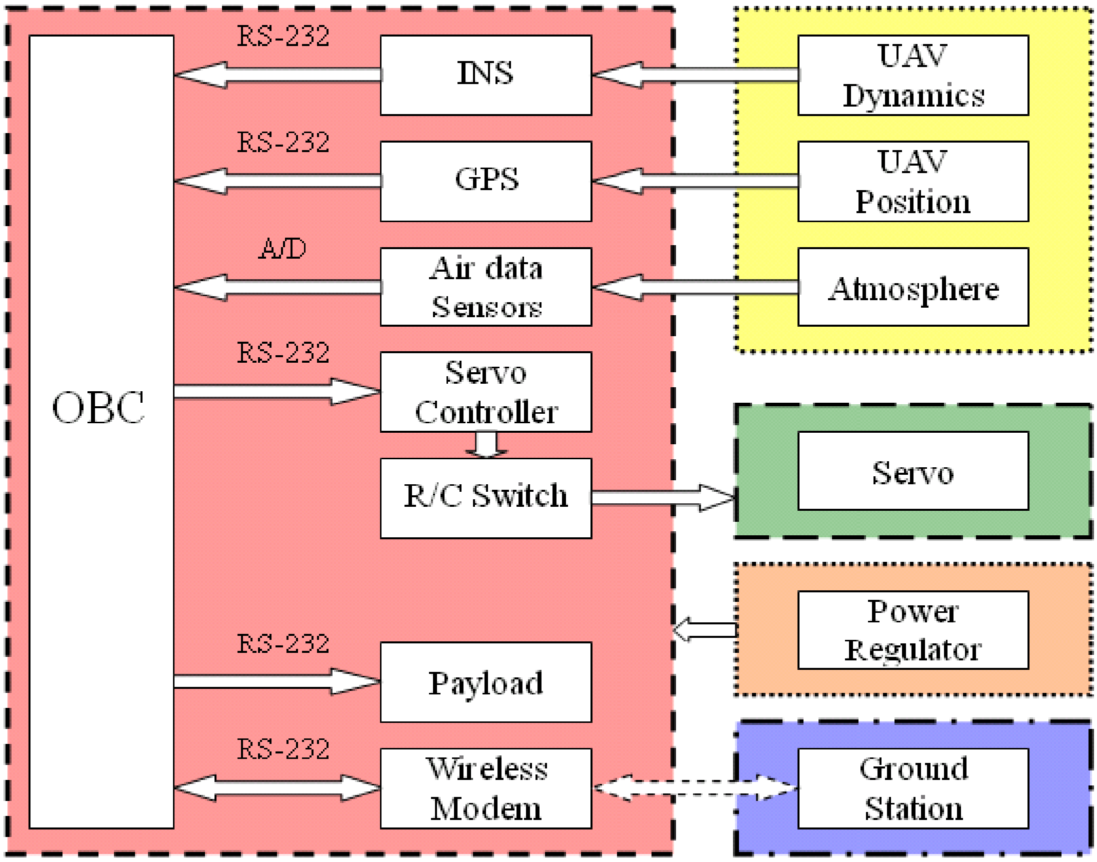


Figure 2-2 Hardware Architecture of Low-Cost Vehicle [9]

From this hardware architecture, it can be found that, the Ground Station can receive and send data via wireless modem to attain the data uplink and downlink between the airborne and ground. To attain the low-cost objective, a laptop is chosen as hardware platform for the ground station.

2.2 Ground Station Display

The major responsibility of Ground Station Display is to track the waypoints of aircraft and report on targets at certain coordinates. Figure 2-3 and Figure 2-4 illustrate the instrument table display and mission control navigational display [10].

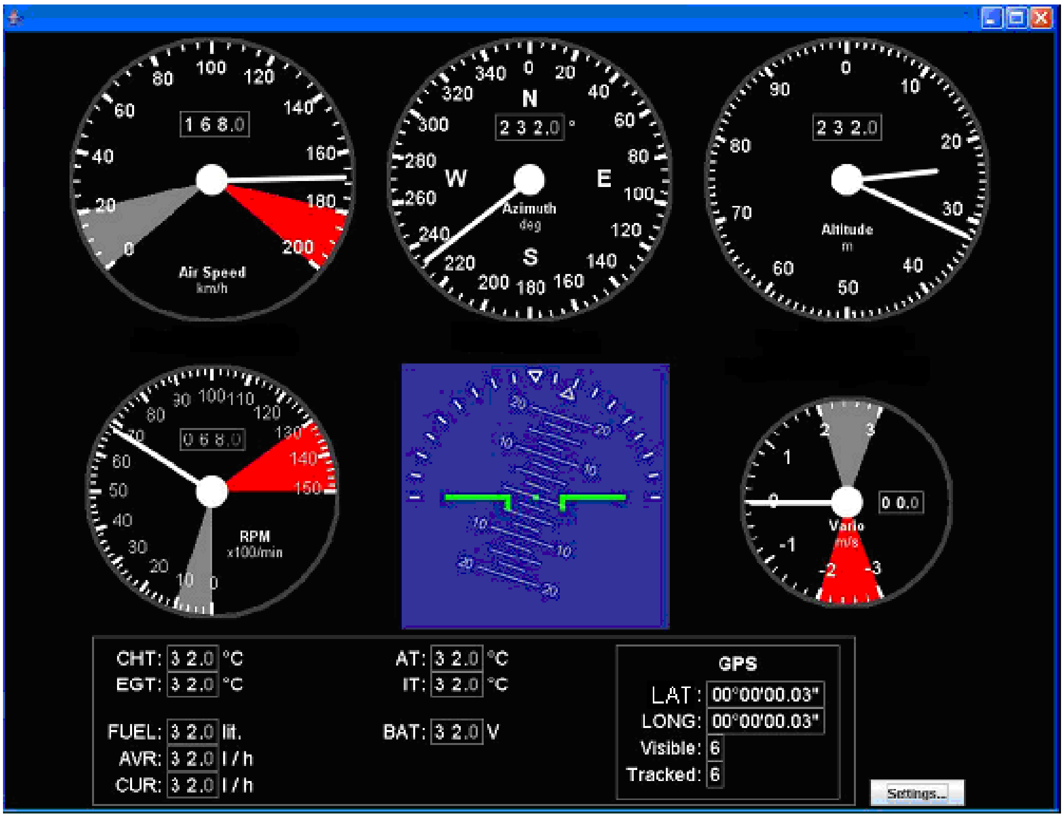


Figure 2-3 Instrument Table [10]

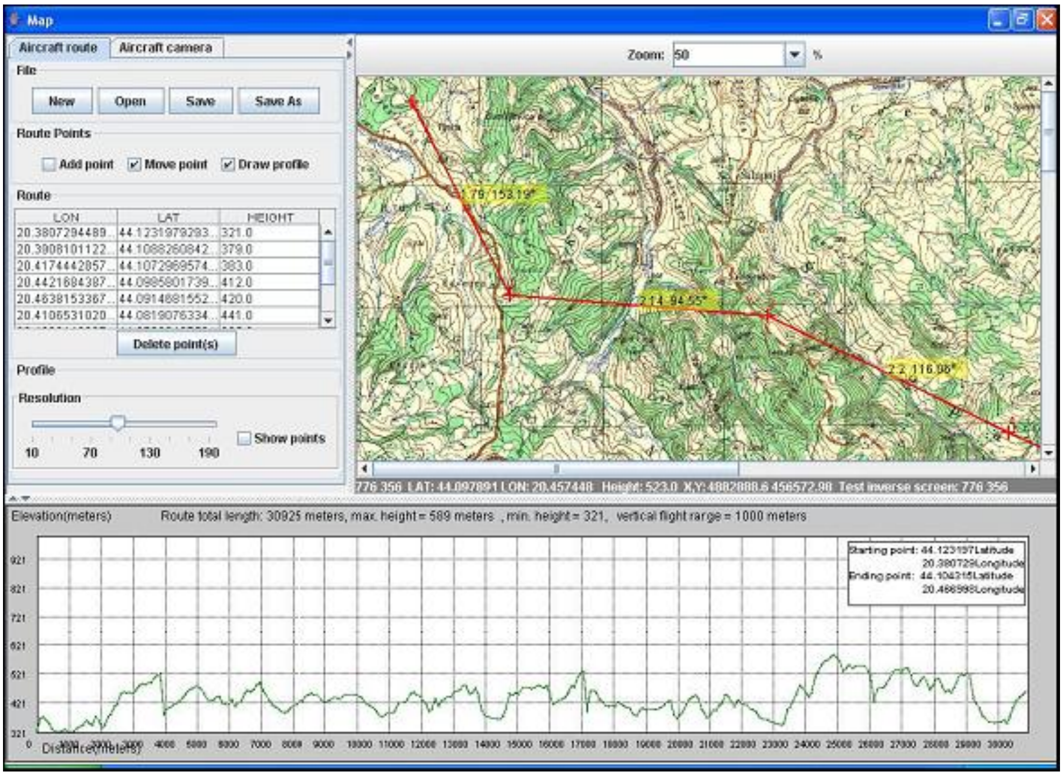


Figure 2-4 Mission Control Navigational Display [10]

The objective of instrument table is to present basic flight data and attitude of the vehicle, and all of these data should be monitored by the operator on ground.

The mission control navigation display contains the waypoints which should be flied over. The waypoints position can be input by operator manually, and the flight route can be calculated on the basis of their positions.

However, too many instrument displays in one frame can induce some blur and add the operator workload. To solve this problem, some other ground station design integrated the instrument table display and mission control navigational display together.

For example, the Ground Station design of Brigham Young University allows for real-time plotting of position (map and waypoints), altitude and airspeed by integrating the map display and instrument table together [8]. The default display interface is shown in Figure 2-5.

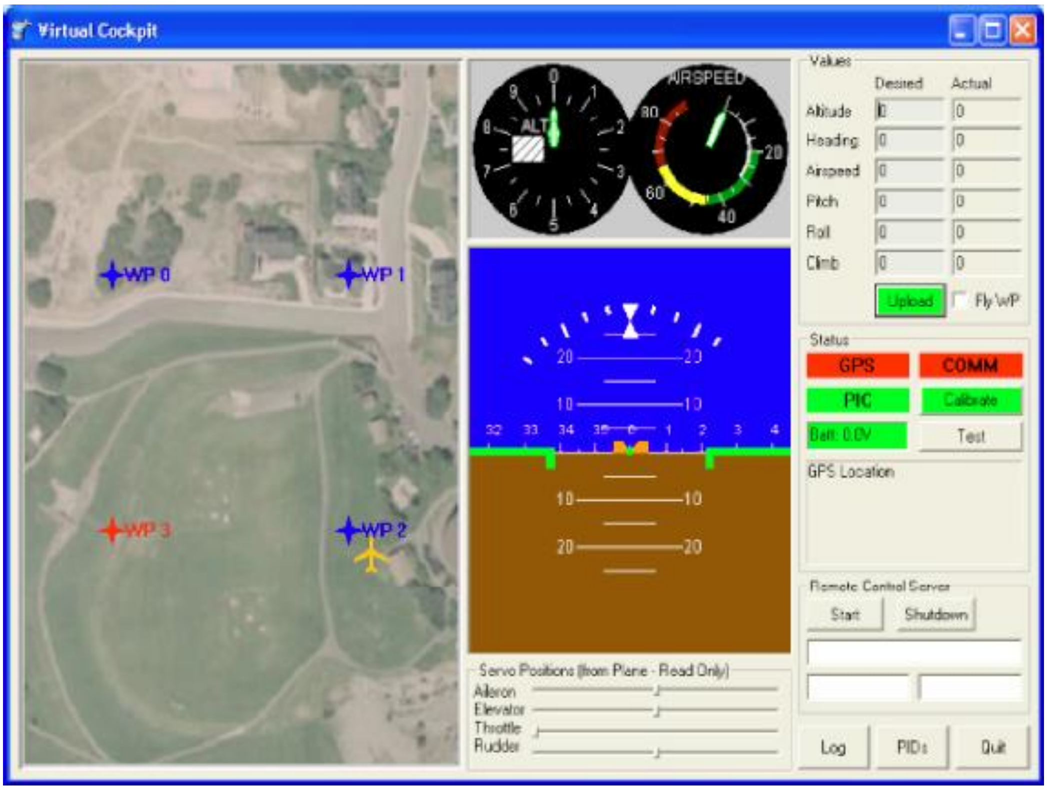


Figure 2-5 Display Interface of Ground Station [8]

Another integrated ground station layout including the monitor panel and map panel [9] is illustrated in Figure 2-6 and Figure 2-7.

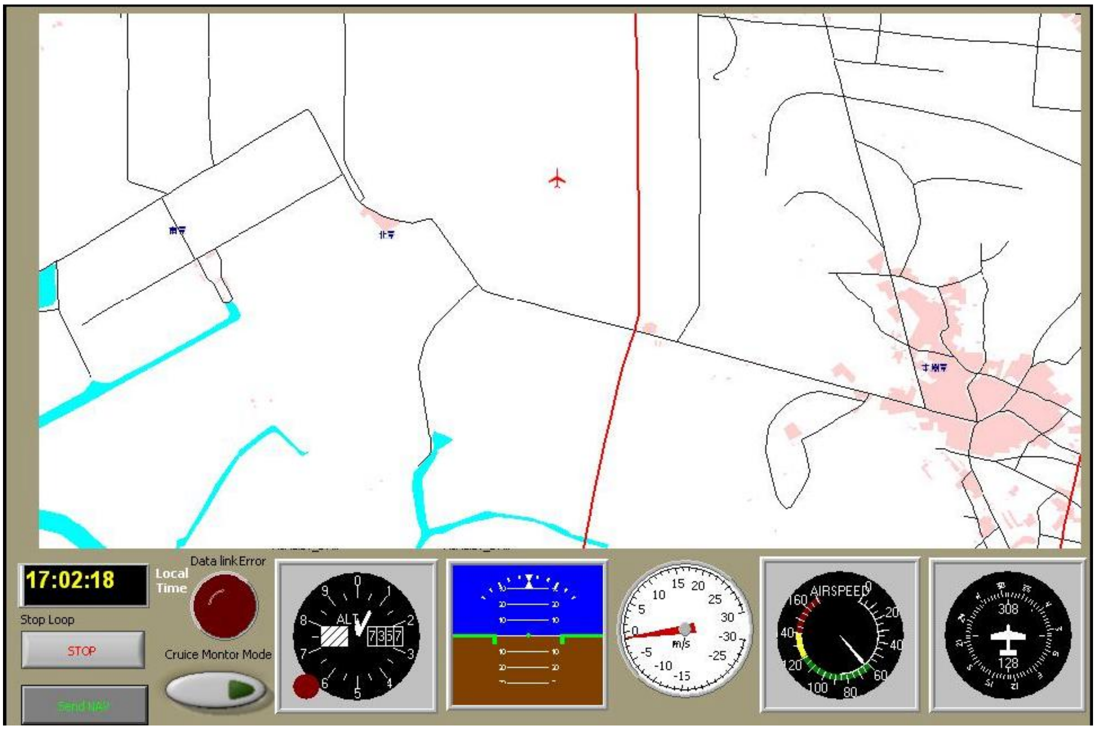


Figure 2-6 Map Panel of Ground Control Station [9]

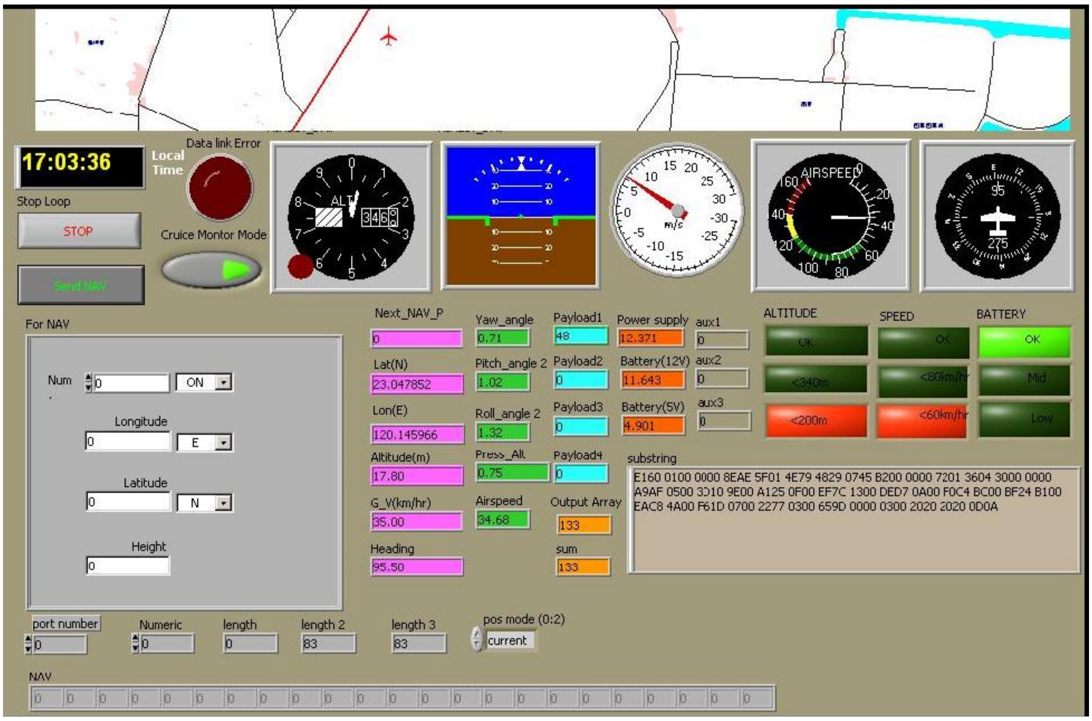


Figure 2-7 Monitor Panel of Ground Control Station [9]

These integrated display layouts can reduce cognitive fatigue and present an intuitive understanding for the operator.

To fulfil the objectives of ground station, the software development is the critical element of the ground station display design. The paper of Kang [11] gave out a typical structure of GS software design which is shown in Figure 2-8 and the software structure supports the bi-directional process.

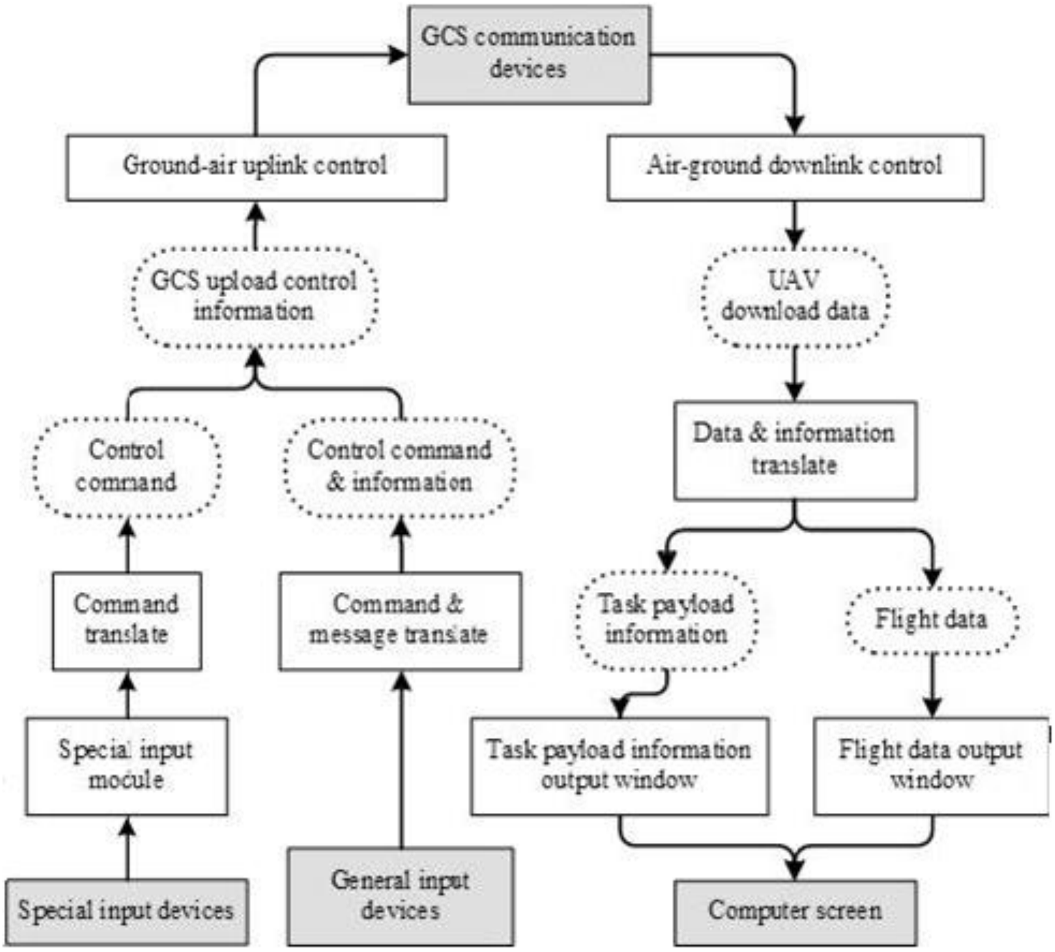


Figure 2-8 Typical Structure of GS software [11]

From this structure, it can be found that a main issue for the software design is to make sure what data & information should be displayed on Ground Station. Therefore, some typical flight data are included in GS software, and their sources and properties were also presented in Kang's paper, which is shown in Table 2-1 [11].

Table 2-1 Data and information for display [11]

Aspect	Class	Source	Property	Examples
Flight control parameter	Space motion	Motion sensor	Para.	Air speed / Altitude / Climb rate / Attack angle
	Attitude	Attitude sensor		Pitch / Roll
Navigation data	Space localization	Navigation module	Para.	Latitude / Longitude / Absolute altitude / Yaw
	Task Information	Task control module	Status / Para.	Target direction / Current Task
	autonomous navigation	GCS software	2D Surface curve	Planned route / Planned route points / Flight Path
Sub-system information	Flight control system	Airborne computer	Status	Autonomous / Half autonomous / Manual
	Flight control device	Airborne sensor	Para.	Actuator output / Control law correction
	Navigation device	Airborne computer	Status / Para.	GPS parameter / Navigation status
	Engine & power	Airborne sensor	Status / Para.	Motor rotation speed / Temperature / Fuel volume / Voltage
	Com-munication device	GCS software	Status	Normal / Error / Disconnect
	Load & other device	Airborne sensor	Status	Payload state / Landing gear state

In paper of Kim [12], a simulation environment was given out for ground control station development which was organized with two major parts: GUI (Graphic User Interface) and communication simulation. The GUI was developed by Mathwork's GUIDE and the communication simulation was developed by the Matlab Simulink to receive the flight information from aircraft.

After the literature study and comparing the advantages and disadvantages of different designs of the ground station display, a new method will be presented for developing the Human Machine Interface for the Ground Station in this thesis.

2.3 Flight Management System

Flight Management System is a fundamental part of avionics systems because it can reduce the pilot workload.

Flight Management System (FMS) is an integrated system that uses navigation, atmospheric and fuel flow data from several sensors and provides a centralized control system for flight planning, flight and fuel management [13]. The main tasks of FMS carried out are as follows:

1. Provision of flight guidance, lateral and vertical control of the aircraft flight path.

2. Monitoring the aircraft flight profile, calculating the optimum speed for each phase of the flight and ensuring safe margins are maintained with respect to minimum and maximum speeds over the flight profile.

3. Automatic engine thrust control.

In addition, FMS plays a major role in the flight planning task, provides a computerized flight planning aid to the pilot and enable major revisions to the flight plan to be made in flight, if necessary, to cope with changes in circumstances.

For the low-cost vehicle, the major function of flight management system on ground station is to provide the path plan which can be followed by air-vehicle.

The architecture of Flight Management of a new framework for Multi-Objective Flight Management of Unmanned Aerial System is given in Figure 2-9 [14].

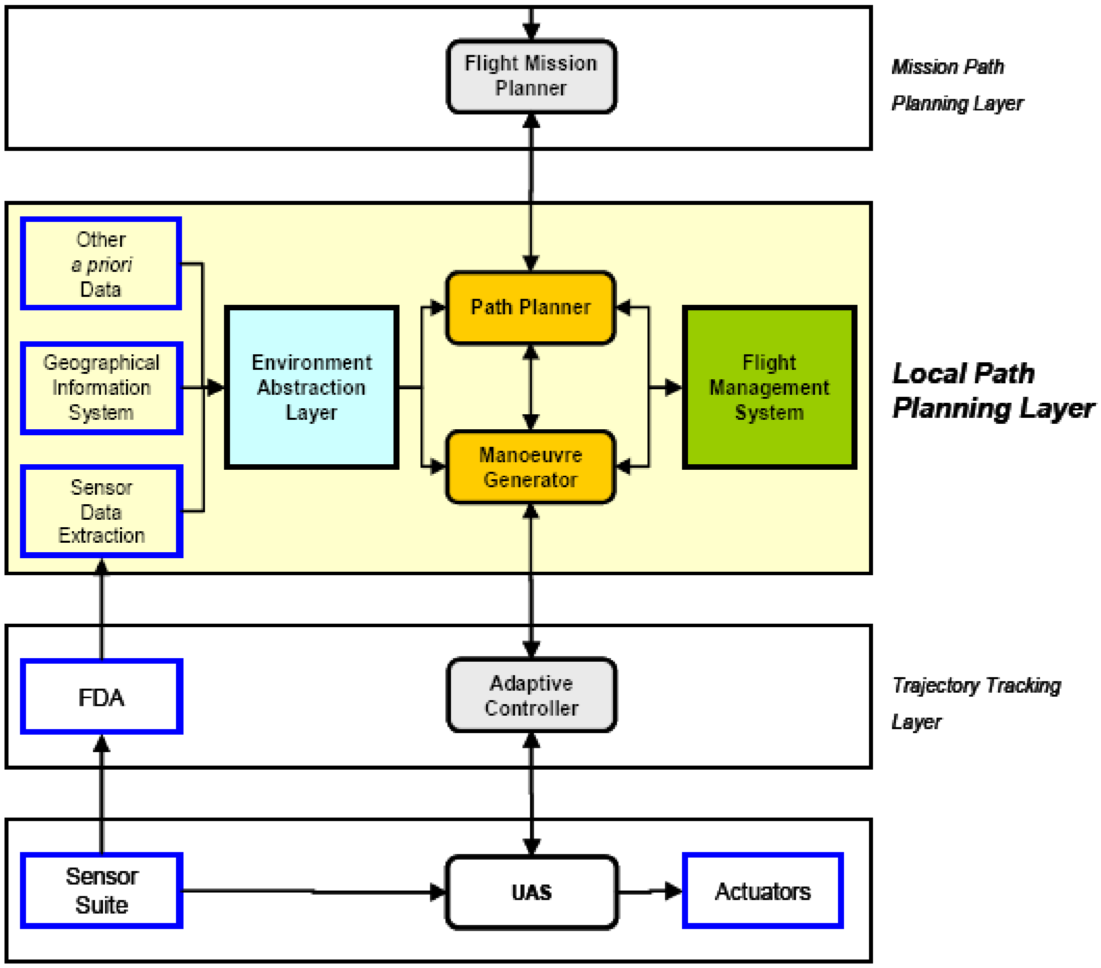


Figure 2-9 Architecture of Flight Management [14]

The management system in this architecture is in charge of the management of all relative layers such as environment abstraction, path planning and so on. In the following sections, some important aspects will be introduced for the flight management system of low-cost vehicles.

1. Path Planning

Path Planning (PP) can give out waypoints comparatively safe and short length. The objective of Path Planning is to design a good path to shorten the path length and reduce threat exposure.

In the paper of Brigham Young University [8], one of the methods of waypoints path planning is to model threats and obstacles as points to be avoided. With threats specified as points, for example, the Voronoi graph will consist of n convex cells, each containing one threat. Figure 2-10 shows an example of a Voronoi graph constructed from point threats.

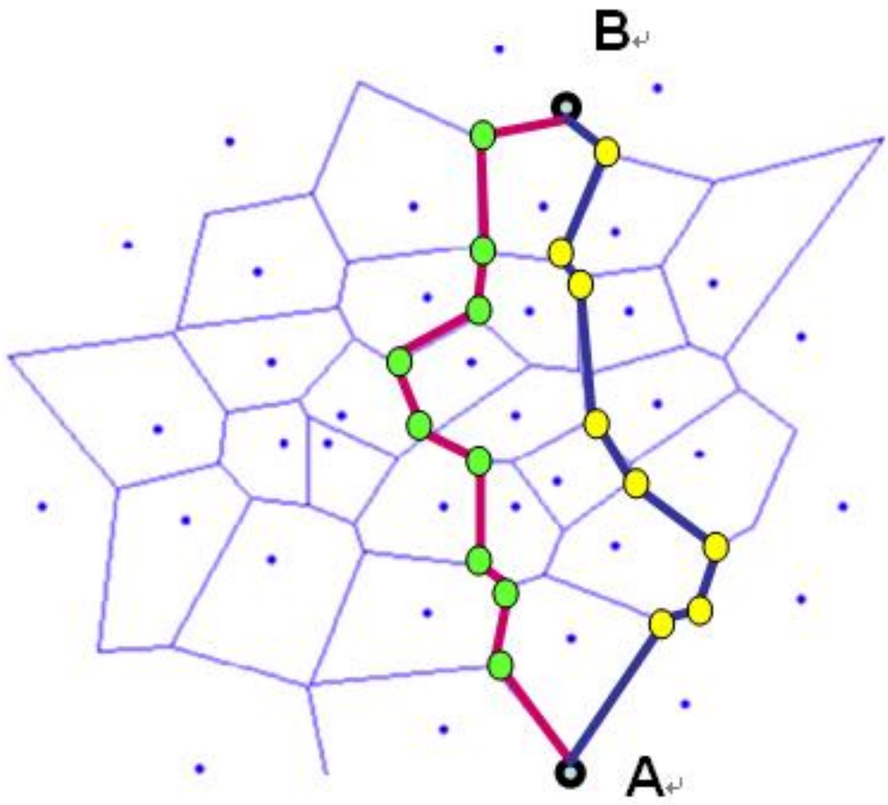


Figure 2-10 Voronoi graph with point threats [8]

In the graph, the edges of the cells have the same distance to each closest threat waypoints. So, the route along the edge is comparatively far from threats. For Example, if the vehicle plans to fly from point A to point B, there will have a lot of choices such as the purple line and blue line marked in Figure 2-10. After calculation, the shortest and low threat exposure path will be chosen. Then the aircraft can fly over the waypoints to follow the path.

Some other materials **Error! Reference source not found.** [15][16][17] also present some algorithms for the path planning. Through these methods, a straight-line waypoint path can be generated.

However, these flight routes are not time-stamped and hard to be followed with dynamic constraints by the vehicles. Therefore, trajectory smoothing needs to be researched further.

2. Trajectory Generation

The objective of Trajectory Generation is to generate a reasonable and smooth trajectory which can be followed by air-vehicle through all the waypoints predefined in path planning.

A lot of Trajectory Smoothing methods are researched and given out by authors [18][19][20]. A C1 Continuous Cubic Bezier Curve for path smoothing is shown in Figure 2-11 [18].

If the aircraft needs to fly from waypoint1, then waypoint2, finally to the waypoint3, it must start turning before reaching the waypoint2 in the actual operation. Four control points (P0, P1, P2 and P3) are needed to make a Bezier curve, where P0 and P3 are the curve endpoints. Through this method, the straight line trajectory in path planning will be smoothed and can be followed by the aircraft real operation.

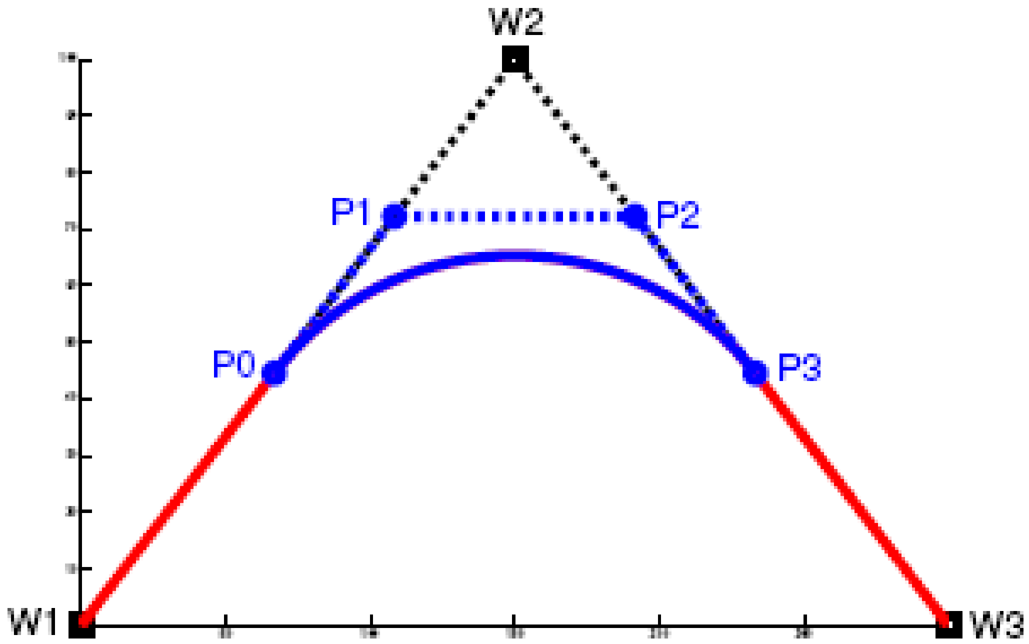


Figure 2-11 C1CBC Path Smoothing [18]

3. Flight Track

The Flight Track provides the guidance logic and method to control vehicle to track the desired path.

New nonlinear guidance logic is demonstrated to guide air vehicles on curved trajectories [21]. This method can be easily implemented and resulted in an excellent tracking performance. A reference point is selected on the desired trajectory, and a lateral acceleration command is generated using the reference point (see Figure 2-12). The lateral acceleration command is determined by

$$a_{s_{cmd}} = 2\frac{V^2}{L_1}\sin\eta$$

V: Vehicle velocity.

L_1: The distance from current position to a reference point.

η: Angle created from V to the line L_1 (clockwise direction is positive).

α_{Scmd}: Acceleration command perpendicular to vehicle velocity direction.

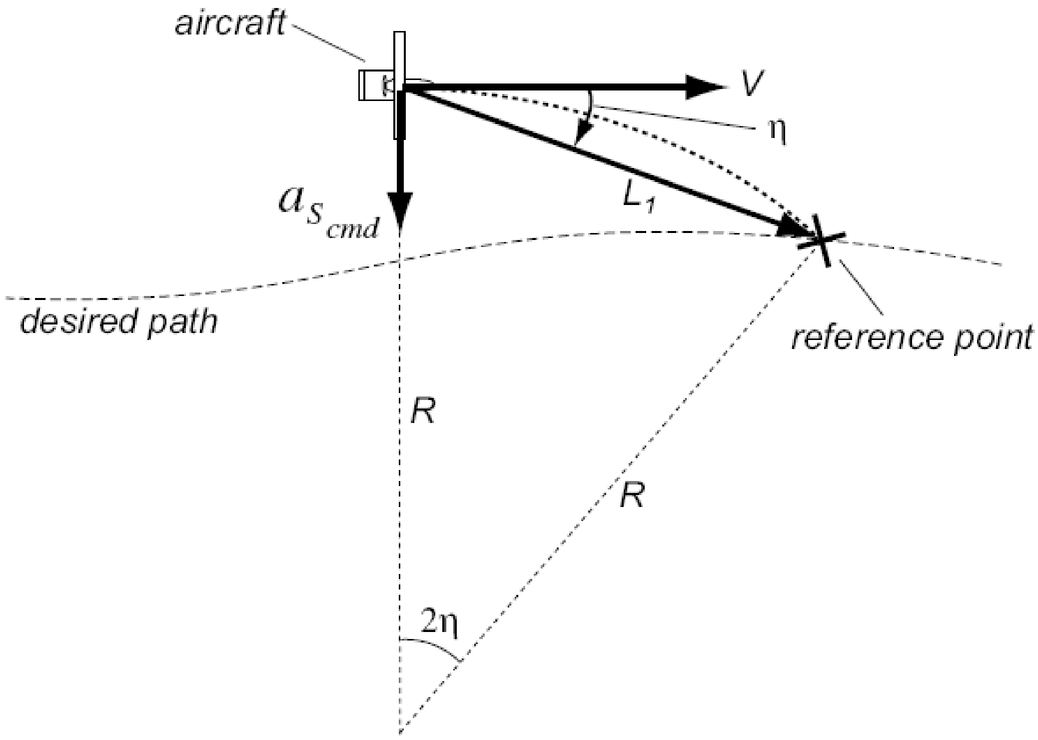


Figure 2-12 Diagram for Guidance Logic [21]

Under the control of the lateral acceleration command, the aircraft can fly from the current actual position to the reference point to catch the desired path which has been planned.

4. Formation Flying

The formation flying is researched for the multi-vehicles on how to keep a certain formation during the flying process and avoid the collision accident.

Some papers developed algorithms for formation flying including static and dynamic obstacles [22] [23]. “Cooperative UAV Formation Flying with Stochastic Obstacle Avoidance” provides how to keep formation and avoid collision and obstacle [23]. In this paper, the proposed control system has a two mode - two layer hierarchical structure.

The two modes are the Safe Mode and the Danger Mode. The vehicles fly in the Safe mode when there are no obstacles in the environment and the vehicles switch to Danger Mode when there are obstacles or chance of collision. Both the modes have a two layer hierarchical structure.

As Figure 2-13 shows, the upper layer is used to generate the reference trajectories and the bottom layer uses a Model Predictive Control (MPC) based tracking controller to follow the reference which generated by the upper layer [23].

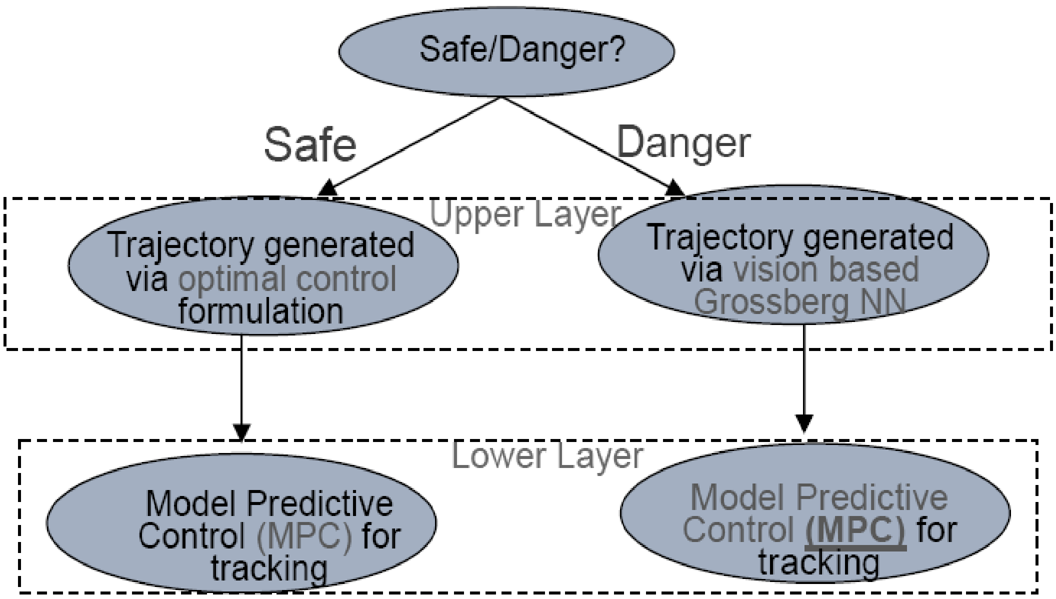


Figure 2-13 Two Layer Hierarchical Structure [23]

3 Methodology of Research

3.1 Software Design Methods

3.1.1 Rapid prototyping model

According to “Software Life Cycle Models [24]”, some development models are commonly used for software development such as waterfall model, incremental development model, spiral model and rapid prototyping model.

The rapid prototyping model was chosen for the design of Ground Station Development. Figure 3-1 shows the development process of rapid prototyping model which includes the following steps:

1. Requirements Definition/Collection

Information collection is usually restricted to a subset of the complete system requirements.

2. Design

Integrate the initial and new requirements information into a new or existing design quickly and build into the prototype.

3. Prototype Creation/Modification

The information collected can be rapidly added into a prototype to create new design on base of current result for modification.

4. Assessment

The prototype can be quickly provided to the user for assessment, then comments and suggestions could be feedback very quickly.

5. Prototype Refinement

The feedback collected from the user is applied to modify the prototype. The designer refined the prototype to make it more effective.

6. System Implementation

In most cases, once requirements are understood, the system is redesigned and implemented at once, until the fully functional system is achieved at last.

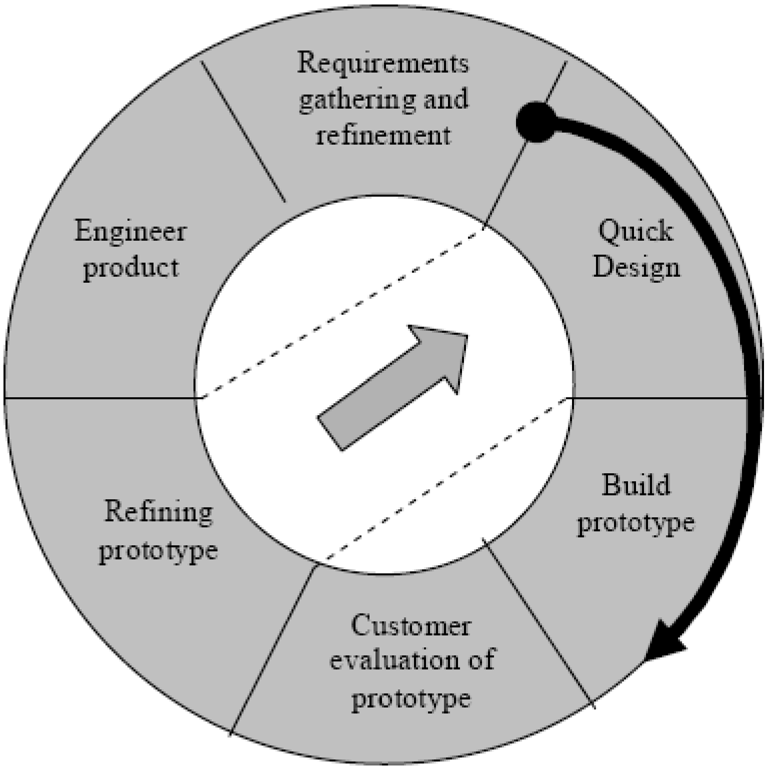


Figure 3-1 Development Process of Rapid Prototyping Model

The advantages of Rapid Prototyping Model are improving system usability, closer match to the system needed, improving design quality, improving maintainability and reducing overall development effort.

The user interface is the crucial part of ground station development that allows a user to control and monitor the system. Therefore, the application of rapid prototyping model can bring benefits to the development of ground station in such a limited time of individual research project. Using this technology, a quick iterative design can be achieved because the design result can be run immediately and the feedback from the users can be attained as soon as possible.

3.1.2 Object-Oriented Design

Nowadays, the object-oriented design has become a major approach for the software design. Object-oriented design is a method of design encompassing the process of object-oriented decomposition and a notation for depicting logical and physical as well as static and dynamic models of the system under design [25].

According to “Software Requirements and Design [26]”, the principle of object-oriented design is to define the objects and the messages interaction among them (see Figure 3-2).

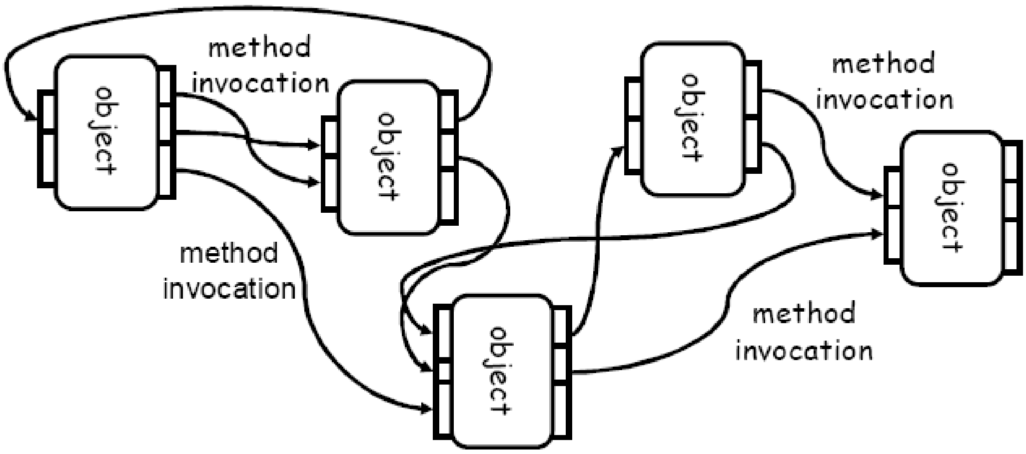


Figure 3-2 Object Oriented Architecture

The software development based on object-oriented design uses objects, not algorithm, as its fundamental logical building blocks.

There are five properties of object-oriented design: class/object, capsulation, inheritance, interface and polymorphism.

Class/object is association of data structures with the methods or functions.

Capsulation means internal data representations invisible to clients.

Inheritance is the ability to extend or override functionality from parent class to subclass.

Interface is to define the functions or operation without implementing them.

Polymorphism is the ability of an object-variable to contain, not only that object, but also all of its sub objects.

In this project, some object-oriented development tools and methods are applied to accomplish the software design.

3.2 Display System Development Environment

Some major development environments have been widely used in recent years for display system especially for Human-Machine Interface development.

1. Open Graphics Library (OpenGL) [27]

OpenGL is a widely used environment for developing graphics applications. It is a convenient application programming interface (API) for graphic design. It provides a series of visualization functions such as rendering, texture mapping, and so on.

2. GL Studio [28]

GL Studio Software developed by DISTI (Distributed Simulation Technology Inc.) in America is an object-oriented rapid prototyping model tool.

By using this powerful and intuitive modelling tool, developer can rapidly create, graphical user interfaces to simulate existing human machine interfaces.

High-quality, reusable C++ source code can be produced by the integrated GL Studio code generator.

3. VAPS [29]

VAPS which is developed by Virtual Prototypes Inc. in Canada is a powerful object-oriented rapid virtual prototyping tool for designing and implementing human machine interfaces.

There are five development parts in VAPS environment:

1. Object Editor (OE): to Create the objects with Aerospace Feature;
2. Integration Editor (IE): to manage data through plugs and channels;
3. State-form Editor (SE): to achieve complex interaction of objects via Spreadsheet-like interface;
4. Runtime Environment (RE): to provide a dynamic and interactive interface to test and validate the application.
5. C Code Generation (CCG): the CCG in VAPS software can generate the standard C code of the design, which makes up the defaults of the separation between the computer simulation and the instrument design.

Nowadays, VAPS has been widely employed by more and more engineers and consumers. By using VAPS, those complex computer's data can be transformed to direct display of instruments.

The advantages and disadvantages of OpenGL, GL Studio and VAPS are illustrated in Table 3-1.

Table 3-1 Compare of development environment

	OpenGL	GL Studio	VAPS
Flexibility	Highest	High	High
Programmer Quality	Highest	High	High
Display Quality	High	Highest	Low
Source Code	Any	C ++	Standard C
Market Share	High	High	High

After comparing these three development environment, VAPS version 6.3 is chosen as the tool for Ground Station development.

VAPS contains one main window with several layouts in which user can build/define graphics, define the logic and compile, and run application in run mode or generate C code for application and run it as an executable as shown in the Figure 3-3.

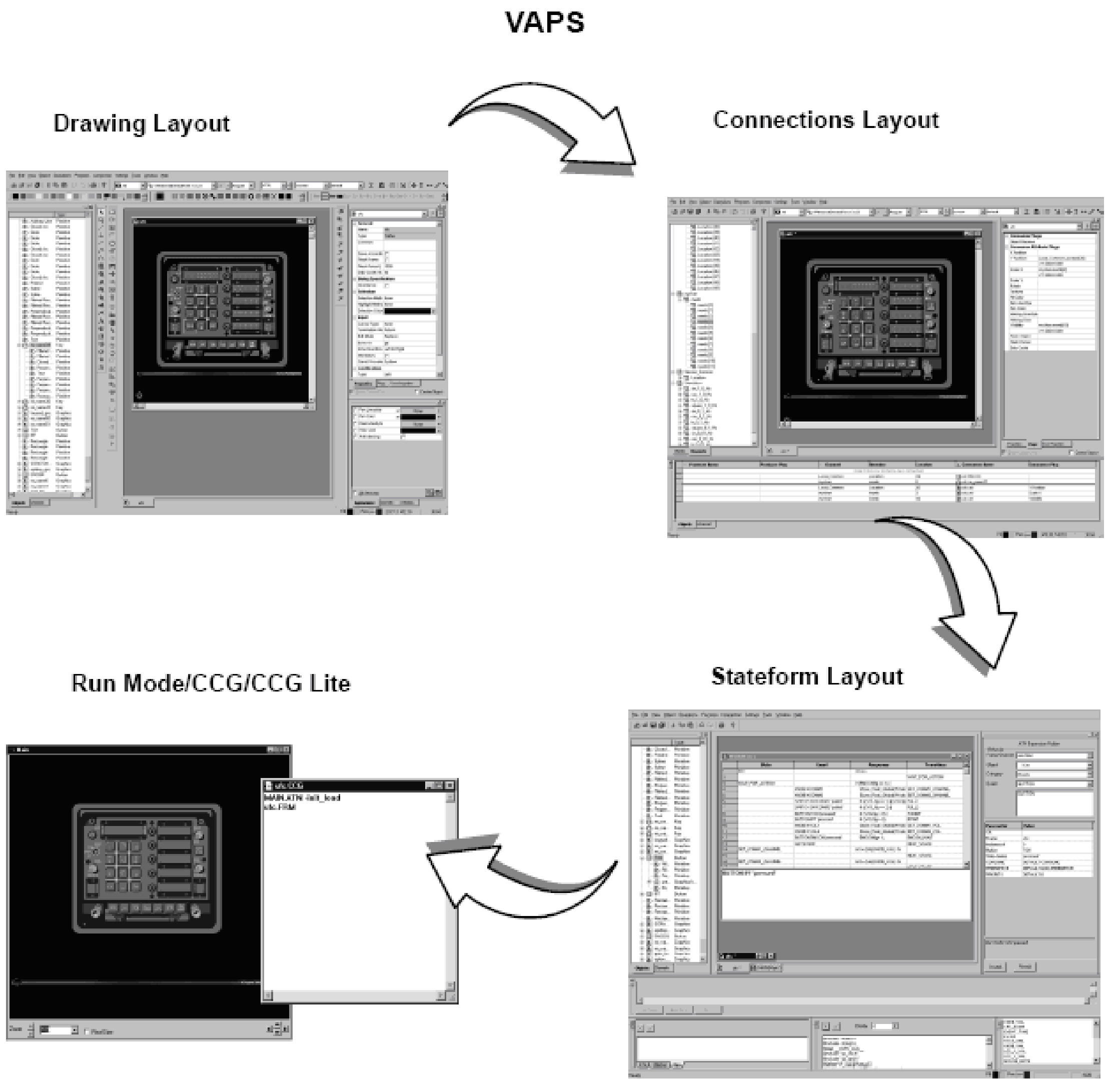


Figure 3-3 VAPS Development Environment [29]

Some more details on how to design the Human-Machine Interface by using VAPS will be given out in Section 4.

3.3 Programming Development Environment

As introduced of Section 3.2, the CCG in VAPS software can generate the standard C code of the design. Therefore, the Microsoft Visual C++ 6.0 is applied as programming development environment to complete some job of data interaction control and communication realization.

Microsoft Visual Studio 6.0 can provide powerful developer tools to develope and debug C and C++ code [30]. It also has a very good interactive development environment interface.

3.4 Flight Management Development Environment

Comparing with some traditional programming languages such as C, C++ and Fortran, MATLAB enables user to execute computationally intensive tasks faster [31]. In addition, the GUIDE in MATLAB is a quick tool to create user own Graphic User Interfaces (GUIs). Therefore, the MATLAB version 7.10.0 (R2010a) is selected for the FMS development.

The Interface of MATLAB GUIDE is illustrated by Figure 3-4.

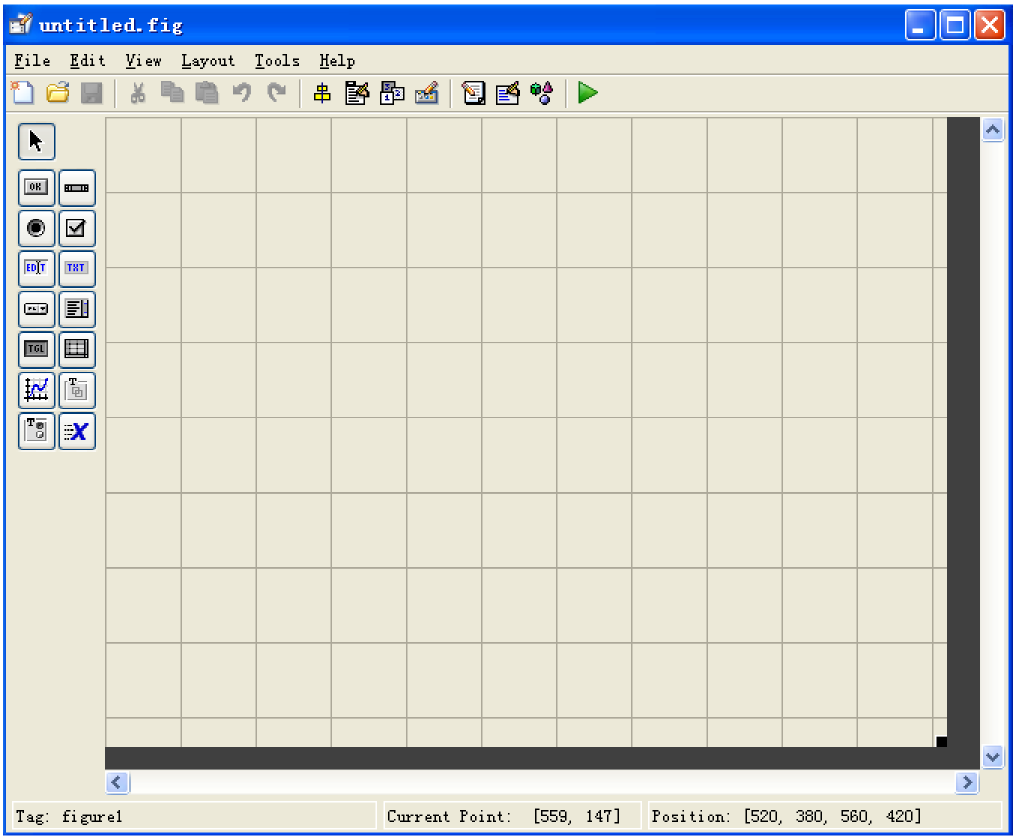


Figure 3-4 MATLAB GUIDE Development Interface

Using MATLAB, the Flight Management System Control Interface will be developed to input the waypoints, generate trajectory and smooth trajectory for vehicle.

3.5 Hardware and Software Architecture

After literature study and methodology research, the basic system hardware and software architectures are presented by Figure 3-5 and Figure 3-6.

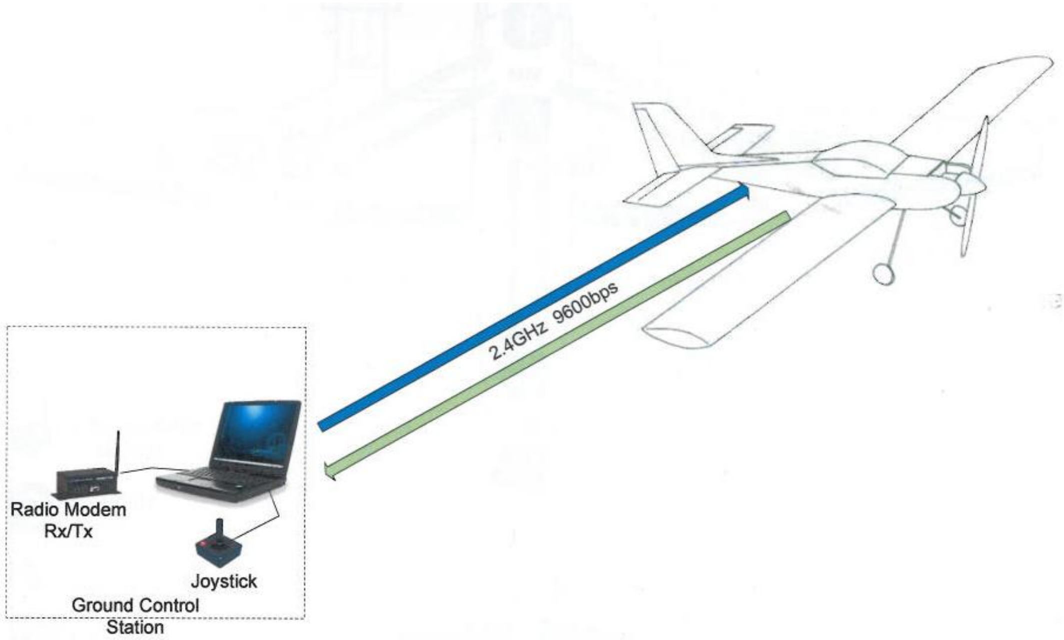


Figure 3-5 System Hardware Architecture [32]

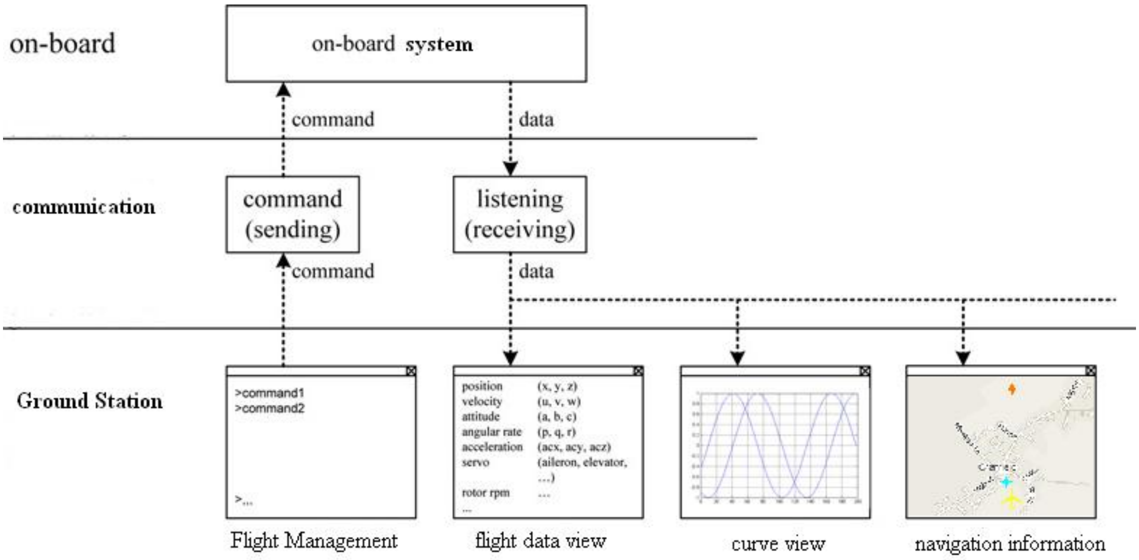


Figure 3-6 System Software Architecture

On base of this hardware and software architecture, the ground station software development is accomplished during the IRP research. The software is running on the laptop PC and includes the Human-Machine Interfaces of display system and flight management control panel.

4 Ground Station Display Design

4.1 System Architecture

The main aim of Ground Station Display Design is to fulfil an easy-use and intuitive Human-Machine Interface for ground station of Low-Cost Vehicle. The system architecture (see Figure 4-1) of ground station display is developed on base of the object oriented design method.

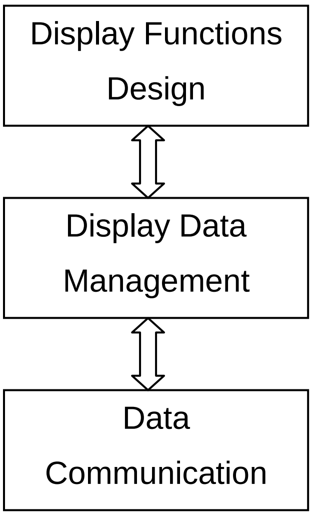


Figure 4-1 System Architecture of Ground Station Display

The system architecture of ground station display is mainly composed of three parts:

1. Ground Station Display Functions

The ground station display functions provide the display of flight data of aircraft, traffic information and some other important information needed to monitor on the ground.

2. Display Data Management

This module is in charge of the display data management and the connections between the received data from onboard system and display objects on ground station.

3. Data Communication

The data communication is responsible for receiving the data via RS 232 serial port from Radio Modem.

4.2 Display Functions Design

Based on rapid prototyping model, a software flow chart of display functions is built as Figure 4-2 shows.

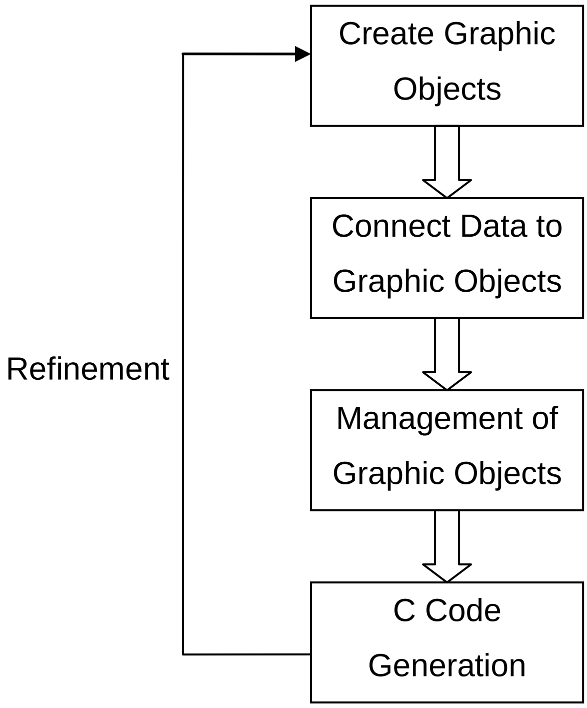


Figure 4-2 Software Development Flow Chart

In this flow chart, every design process includes four steps: Create Graphic Objects, Connect Data to Graphic Objects, Management of Graphic Objects and C Code Generation.

After the assessment for each design result, a refinement will be performed to improve the design for satisfying the full requirements.

The advantage COTS tool — VAPS is applied to achieve the development of ground station display system. As introduced previously, VAPS is a powerful object-oriented rapid virtual prototyping tool. The following parts will present how to achieve the development of ground station display by using VAPS.

4.2.1 Create Graphic Objects

Create graphic objects is the process of creating and assembling basic shapes into a representation of the desired objects in the drawing layout of VAPS. Each graphic object has own shapes, attributes and properties. The display design process of ground station is illustrated in Figure 4-3.

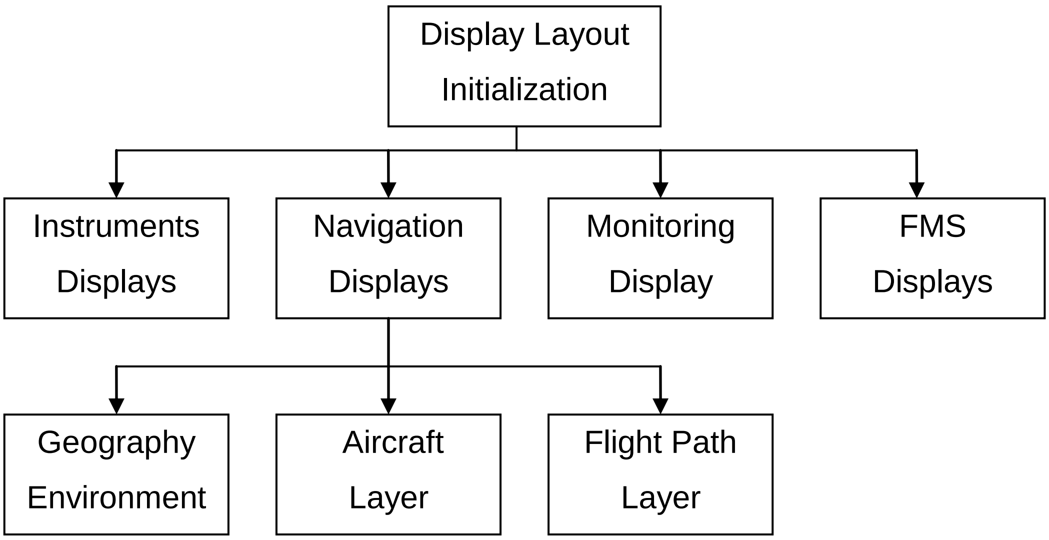


Figure 4-3 Display Design Process

1. Instruments Displays

The instruments displays include the altitude, air-speed and attitude (pitch, roll and heading).

The altitude and air-speed displays are designed as "DIAL" objects in VAPS Object Editor. Meanwhile, the digital numbers are also designed in the middle to display the accurate value of altitude and air-speed (see Figure 4-4).

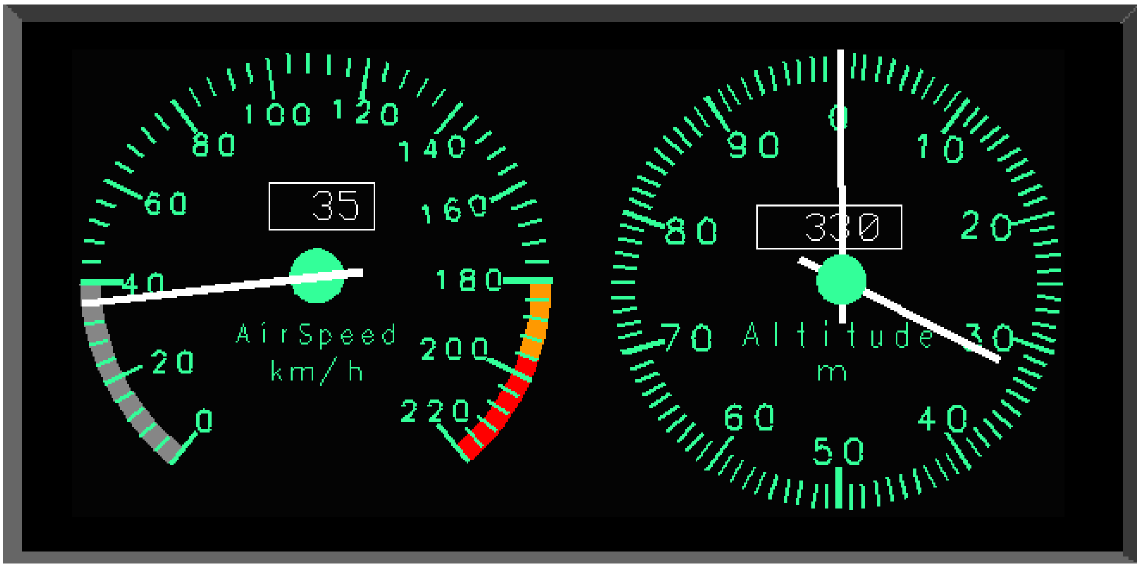


Figure 4-4 Altitude and Air-Speed

The attitude director indicator is shown in Figure 4-5. The display of pitch and roll is designed as “ADI” object and the heading is designed as “TAPE” object in VAPS Object Editor. The attitude display use a blue colour above the horizon line for representing the sky and a brown colour below the horizon line for representing the earth.

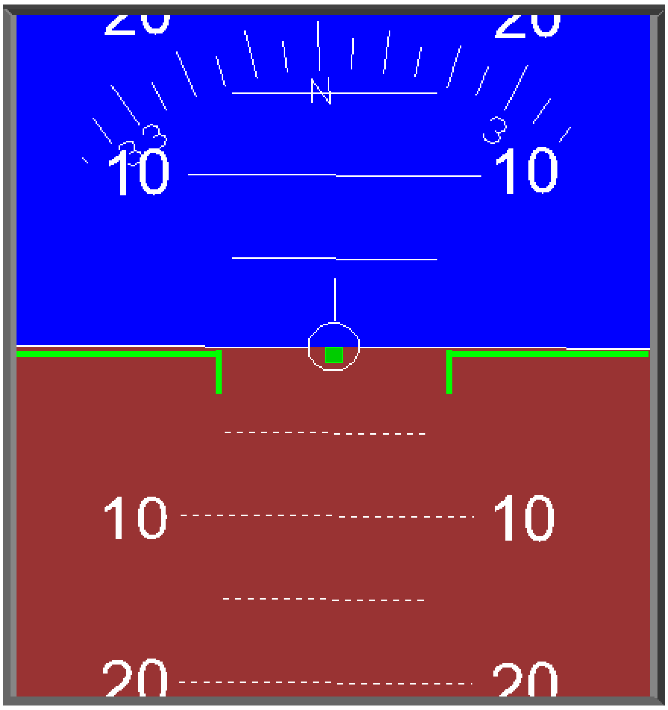


Figure 4-5 Attitude Director Indicator

2. Navigation Information Displays

The Navigation Information Displays applied multi-layer displays technology. It includes the following layers:

- Geography Environment Layer

The objective of geography environment layer is to provide geographical information and a visual reference for moving objects. A map display is a good way to show the aircraft position relative to the waypoints, flight path and the location in a certain terrain. Therefore, how to add a colour moving map into the Ground Station display is a key technology in the navigation display implementation. A quick and simple resolution is applied for the overly active map display. For moving map applications, a “CRT” object is designed and behaves like a camera held over an image，that means, by moving the “CRT” can view a different area of the image. By changing the CRT’s viewing range can zoom in or out on the image; and can show a new orientation of the image by rotating the CRT. In this way, the displays themselves can be controlled indirectly, through the manipulation of the CRT.

- Aircraft Layer

The aircraft layer is to show the aircraft current position. Create the appearance of aircraft and design it into “GRAPHICAL OBJECT”.

- Flight Path Layer

The flight path layer includes the waypoints and planned flight path. The design is similar to aircraft layer: Create the appearance of waypoint and design it into “GRAPHICAL OBJECT”.

The Navigation Information Display is shown in Figure 4-6.

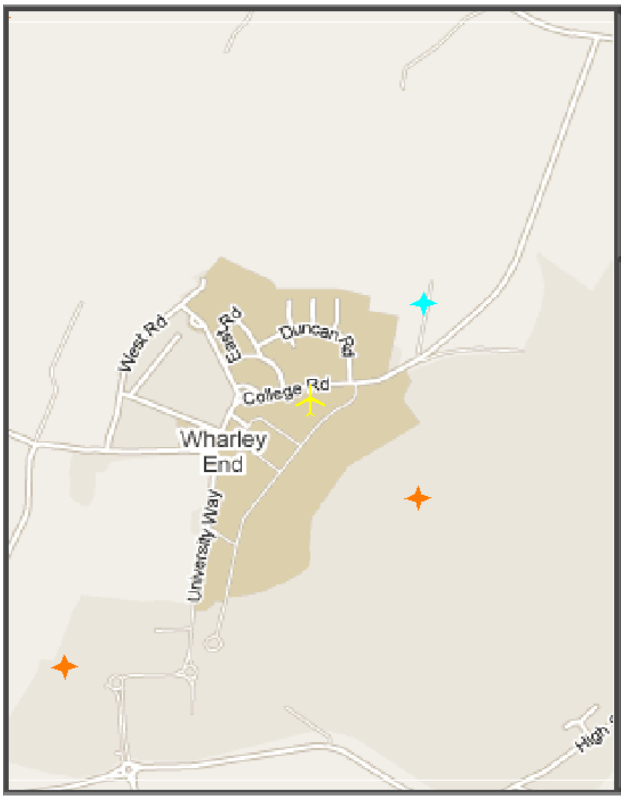


Figure 4-6 Navigation Information Display

3. Status Monitoring Displays

Status Monitoring Displays include data status, communication status, battery monitoring and flight time display.

The Desired, Actual Data and Flight Time displays are designed as “OUTPUT_FILED” object. The “COM” and “SIM” status controls are designed as “BUTTON” objects” to control the communication and simulation. The “Battery” is designed as “LIGHT” object to show the volume of battery. The Status Monitoring Displays are illustrated in Figure 4-7.

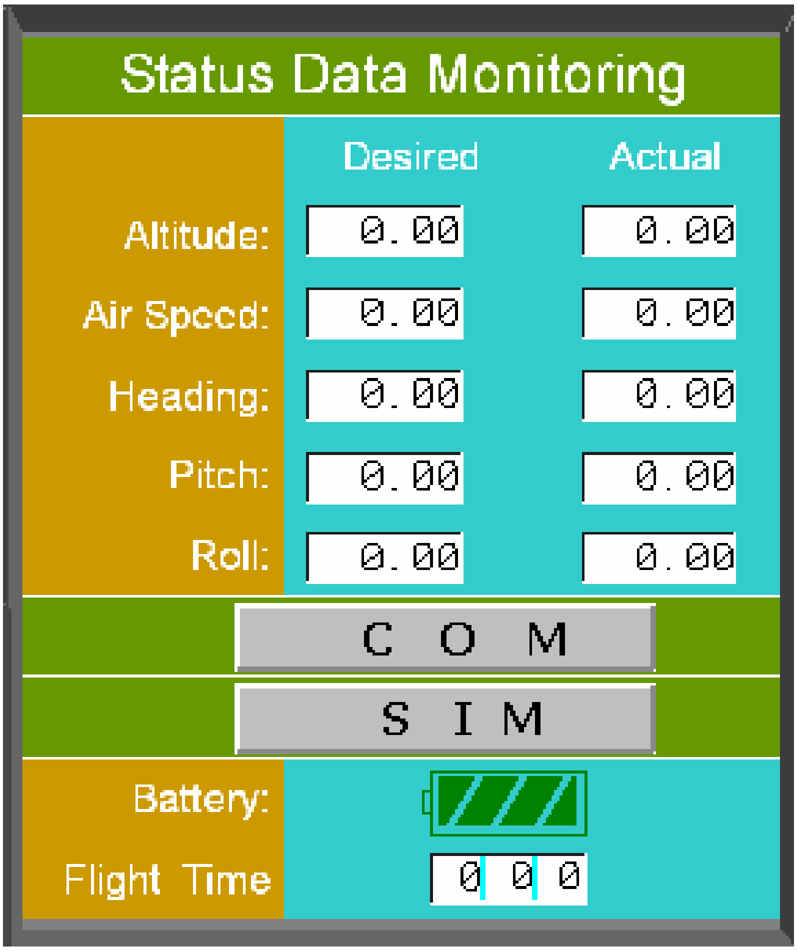


Figure 4-7 Status Monitoring Displays

4. Flight Management Displays

In flight management displays, two “PLOT” objects are designed to display the lateral and vertical flight profile of vehicle as Figure 4-8 shows.

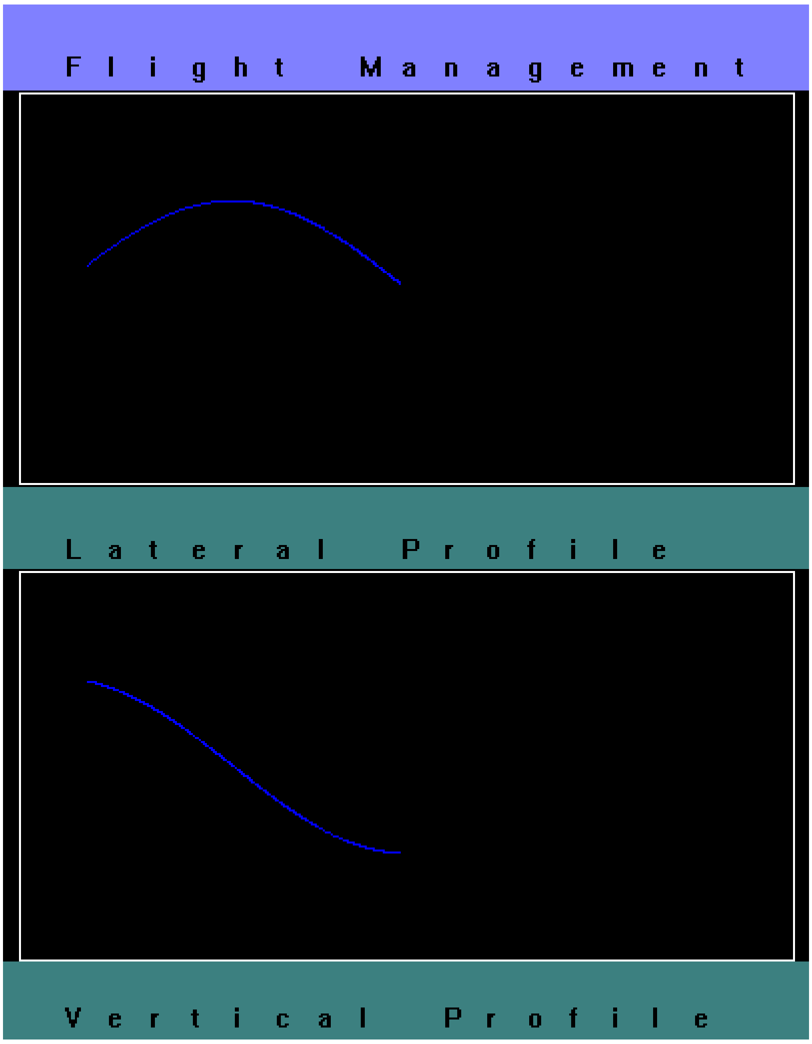


Figure 4-8 Flight Management Displays

4.2.2 Connect Data to Graphic Objects

To drive the movement of the display objects with the flight data of vehicle, the altitude, air speed, pitch, roll and heading data need to be connected into the plugs of each object. The channel data and property are illustrated by Table 4-1.

Table 4-1 Channel Data and Property

Number	Channel_Member	Data Type
1.	Desired_Altitude	float
2.	Desired_ AirSpeed	float
3.	Desired_Pitch	float
4.	Desired_Roll	float
5.	Desired_Heading	float
6.	Actual_Altitude	float
7.	Actual_ AirSpeed	float
8.	Actual_Pitch	float
9.	Actual_Roll	float
10.	Actual_Heading	float
11.	Battery_Volume	short integer
12.	Flight_Time_Hour	short integer
13.	Flight_Time_Min	short integer
14.	Flight_Time_Sec	short integer
15.	Desired_Latitude	float
16.	Desired_Longitude	float
17.	Actual_ Latitude	float
18.	Actual_ Longitude	float

According to the data and property, the "GSCHANNEL" is designed and connected to the relative plugs in VAPS Integration Editor. The structure of "GSCHANNEL" is shown in Figure 4-9.

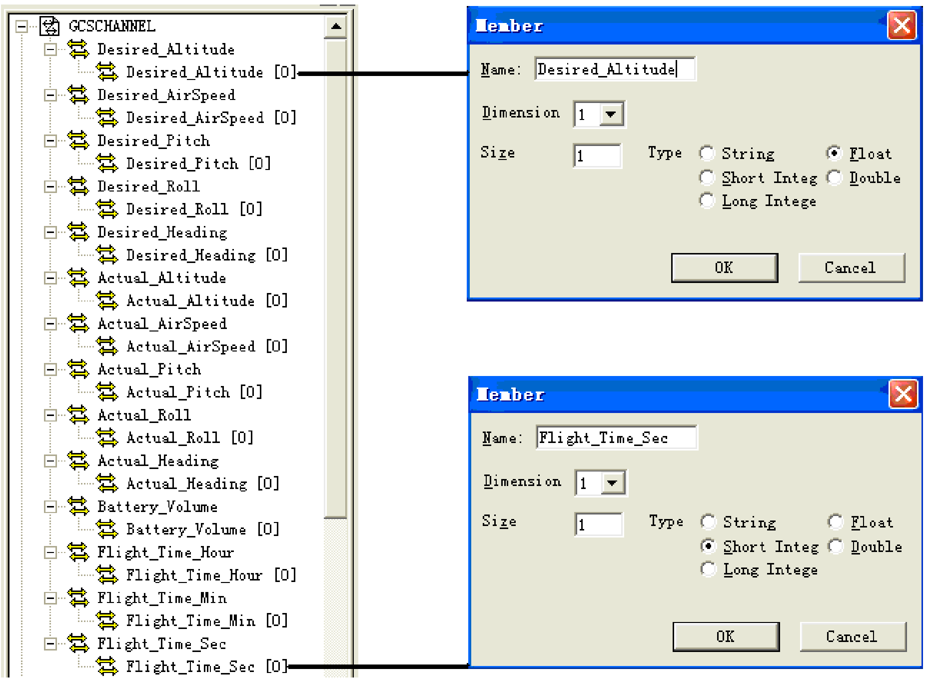


Figure 4-9 Channel Design in VAPS

Each channel member needs to be connected to the relative plug correctly, because it is critical for the communication between the object and the external control program. For example, to drive the altitude needle, the channel member "Altitude" must be connected to the Consumer Plugs Value of the Dial Object for altitude display.

4.2.3 Management of Graphic Objects

Augmented Transition Network (ATN) model is applied in VAPS to achieve the management of all display interactive. Figure 4-10 shows a model of a system which consists of a collection of labelled states with recognized events and transition arcs.

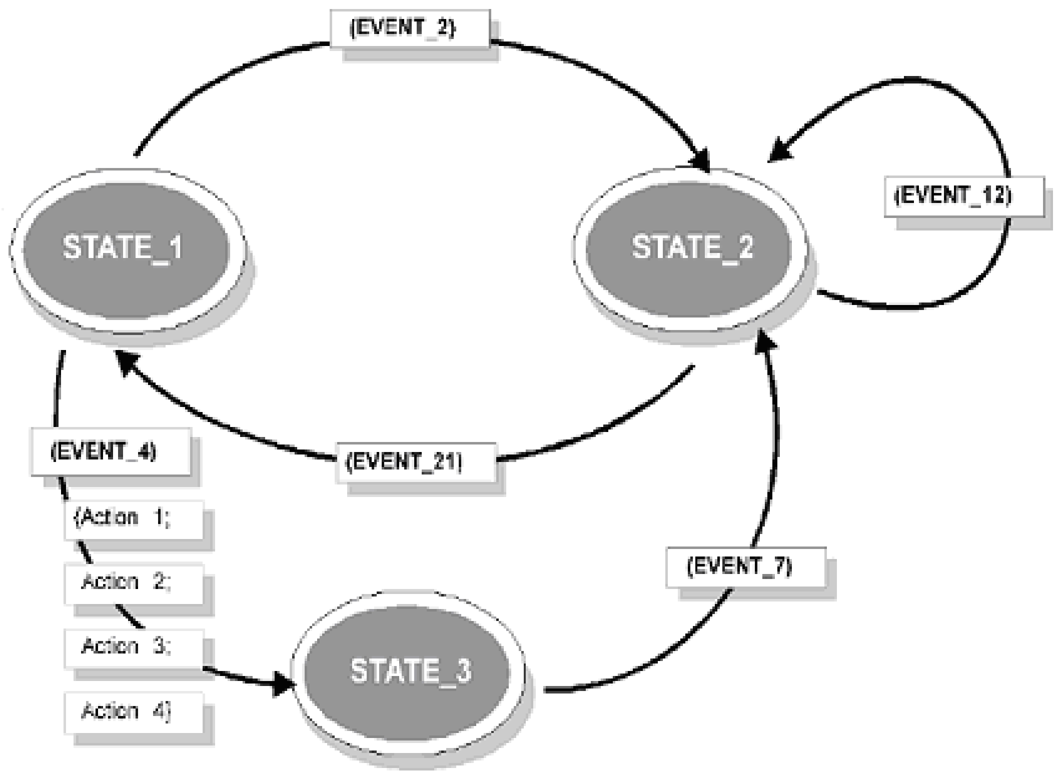


Figure 4-10 Augmented Transition Network Model

The following terms are essential to creating ATN logic programs to control the runtime interaction of application.

1. State： One of a finite number of internal configurations of a system.

2. Event ：An input to which the system may react.

3. Action ： The system’s response to a specified event.

4. Transition：The passage of the system to a new state, as a result of new inputs.

The essential of display management is to initial the layout of all display objects, then load the different display frames such as instruments displays, navigation displays, status monitor displays and flight management displays. All of this display frames are loaded as “FOREGROUND_FRAME” in VAPS.

For the navigation displays frame, it includes three display layers: geography environment layer, aircraft layer and flight path layer. The geography environment layer should be loaded as “MAP_FRAME” and the aircraft layer and flight path layer should be loaded as “FIXED_ICON_FRAME” in VAPS Statement Environment.

4.2.4 C Code Generation

The C Code Generator (CCG) takes all of the files designed in the VAPS and produces corresponding C source code. The generated source code is then compiled and linked with a main module, support libraries, and any user-specified modules to create an executable program, as shown in Figure 4-11 [29]:

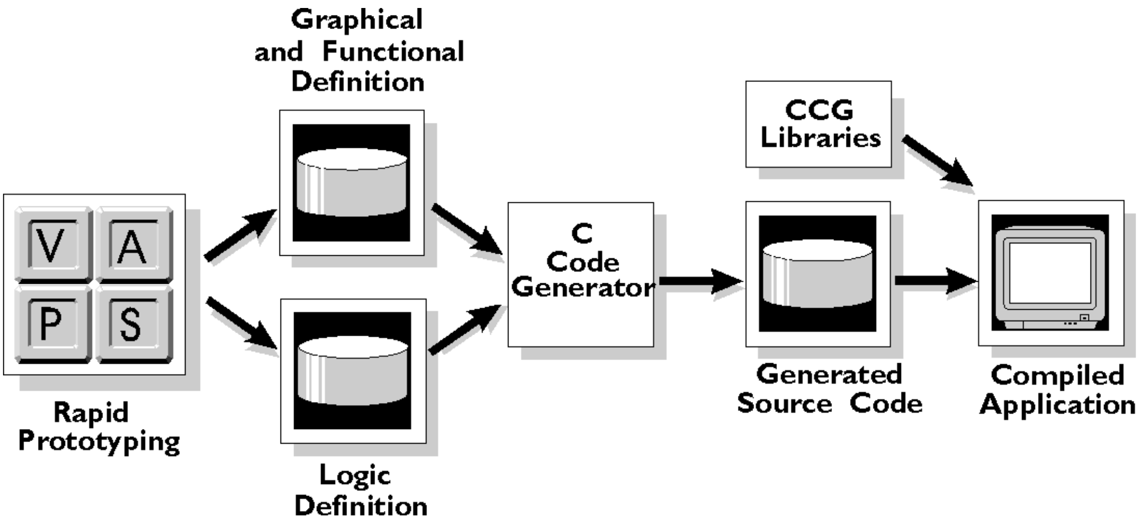


Figure 4-11 C Code Generator

The CCG Process is illustrated in Figure 4-12. It includes four main parts:

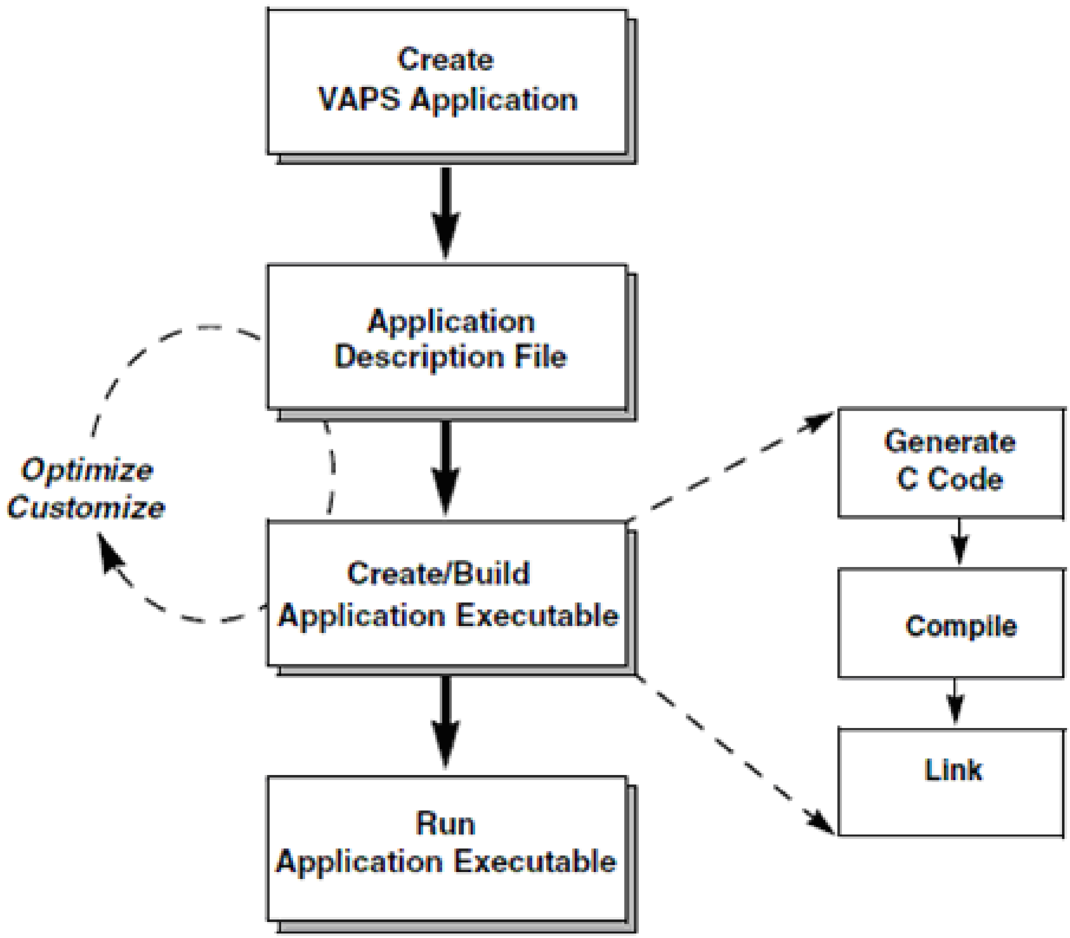


Figure 4-12 C Code Generator Process

1. Create VAPS Application.

The first step of CCG is to complete all design needed in the VAPS environment including the frames, ATNs and channel files design as introduced previously.

2. Create Application Description File

Create the Application Description file (.CCG) listing the contents of application in terms of its frames, ATN and other components, as well as any special options to be used when generating C code for the various components.

3. Create/Build Application Executable

After the .CCG file is produced, create the application executable from “CCG -> BUILD -> REGULAR”. After CCG is built, each ATN, frame and channel of application will have a single C module generated from it. Frames and channels have a header file generated as well. A single C module is generated to describe the VAPS Attribute Tables, and a final C module is created which serves as glue to pull the various generated modules together. The very useful .mak file and .exe file are also created.

4. Run Application Executable

Lastly, the application executable can be run in a non-VAPS environment. Open the .mak file in Microsoft Visual C++ environment and create a new project. It contains main module, initial module and the modules from ATN, frame and channel. The new project can be compiled, linked and run in the standard environment which is independent of VAPS development environment.

4.3 Display Data Management

The objective of display data management is to link the received flight data in external application with the display graphic objects in VAPS.

Within VAPS, Fast channel buffers are stored in a memory segment which is shared by VAPS and the ATN tasks. The communications library provides a mechanism to allow an external application running on the same host as the VAPS or CCG application to attach itself to this shared memory segment. This allows the external application and VAPS or CCG application to share Fast channel data.

Figure 4-13 shows the supported interconnections for shared memory communications. The last one, the share member between CCG and external program is used to implement the message interactive between display functions design and data management.

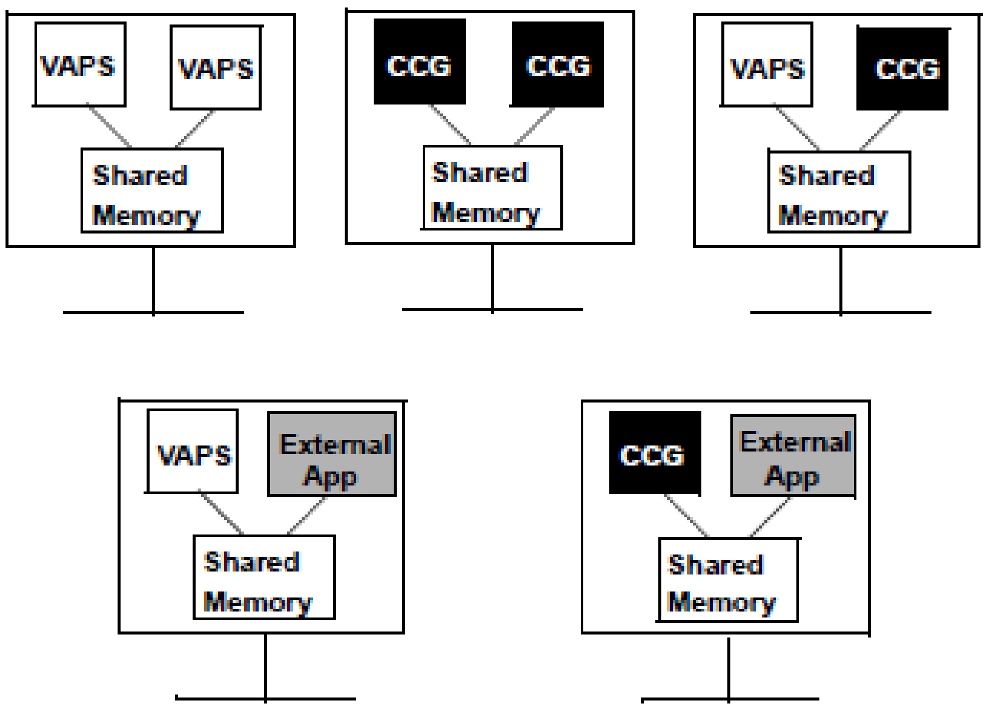


Figure 4-13 Share Member Communication

To achieve the communication between CCG and external application, some VAPS library functions need to be configured in the external application which includes ipcwin.lib, msg.lib, osi.lib, regexp.lib, sim_util.lib, vpcomm.lib, vpi.lib, vpimsg.lib and vputl.lib.

All of these VAPS communication libraries support inter-process communications using shared memory communications. This eliminates the overhead associated with network communications. Shared memory communications is usually the fastest available communications medium.

The flow chart of external application is illustrated in Figure 4-14.

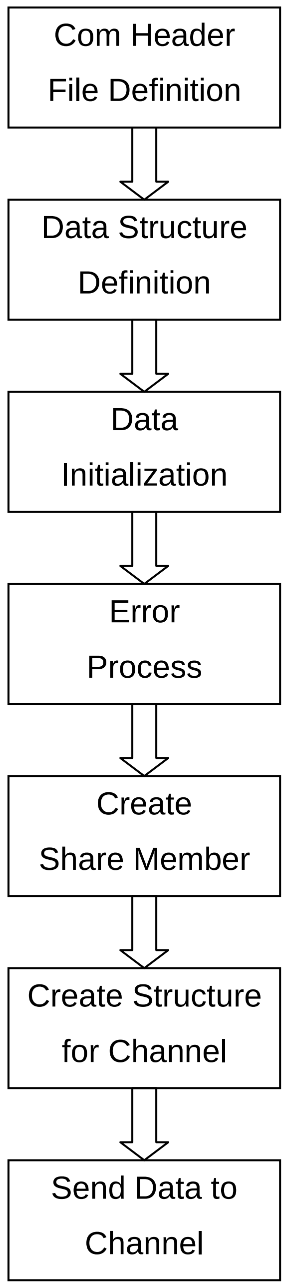


Figure 4-14 External Application Development Flow Chart

There major steps for the external application design are as follows:

1. Communication header file definition

   #include "comm_xface.h“

   This is VAPS communications header file.

2. Data Structure Definition and Initialization

   The Data Structure must have exactly the same value with the Channel design in VAPS. For example, the channel designed in VAPS is shown in Figure 4-15, and the external application must be designed as:

```
 typedef struct struct_to_re {

    float Desired_Altitude;

    float Desired_AirSpeed;

    float Desired_Pitch;

    float Desired_Roll;

    float Desired_Heading;

    float Actual_Altitude;

    float Desired_AirSpeed;

    float Actual_Pitch;

    float Actual_Roll;

    float Actual_Heading;

     short Battery_Volume;

     short Flight_Time_Hour;

     short Flight_Time_Min;
```

short Flight_Time_Sec;

} Struct_To_Re;

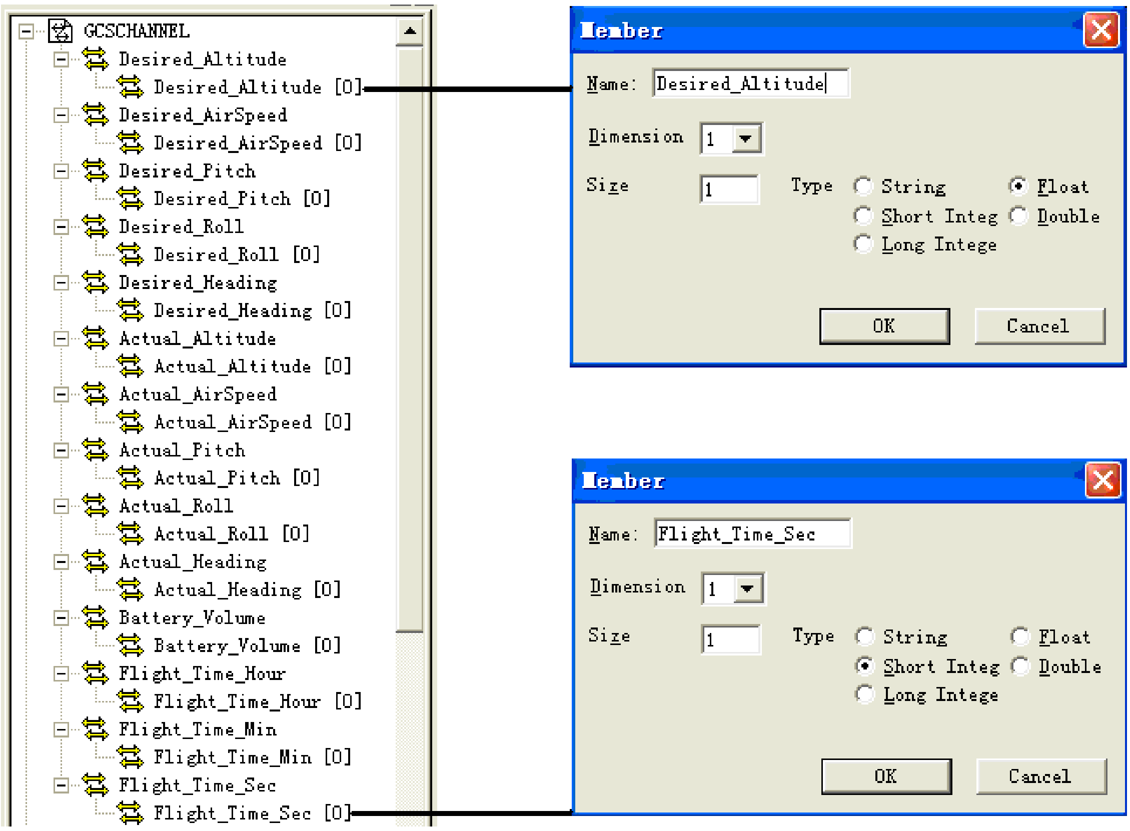


Figure 4-15 Channel Design in VAPS

3. Error Process

Using “cerr_show_errors(TRUE,NULL);” statement to report the errors.

4. Create share-memory

Using “create_vaps_chan_shmid(64 * 1024, 0); “ statement to allocate a block of shared memory with size of 64 * 1024.

5. Create Structure for Channel

Using “Chan_create();” statement to read the channel file and create a "Channel” data structure for the channel, and returns a pointer to the new "Channel" structure.

6. Send Data to Channel

Send data to new "Channel" structure to drive the movement of graphic objects.

After all of these design, the display data in the external control program can be interactive with graphic objects in VAPS.

4.4 Data Communication

The data communication design is to complete the communication between the laptop and Radio Modem via RS232 serial port as shown in Figure 4-16.

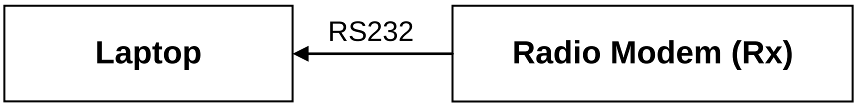


Figure 4-16 Laptop-Radio Modem Interface

Because the laptop has no RS232 port, the first step is the driver installation. PL-2303 Driver [33] is a driver to transfer RS232 port into USB port.

The second step is Communication Files Configuration. Copy all of required communication library into relative directory.

The data communication design flow chart is illustrated in Figure 4-17.

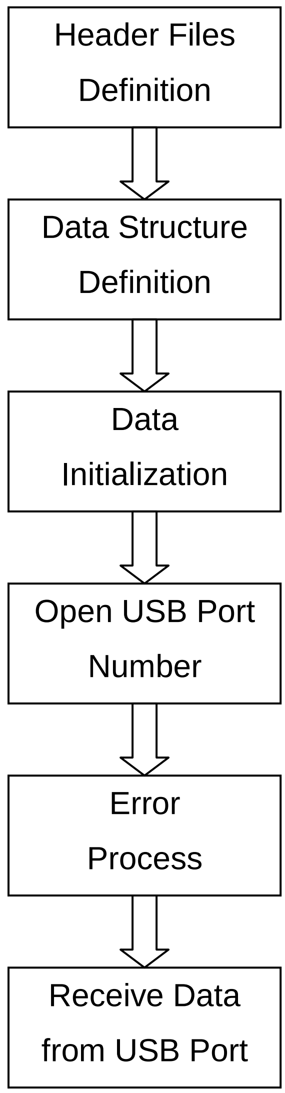


Figure 4-17 Data Communication Flow Chart

In the external program, the RS232 communication codes on base of this data communication flow chart should be added to achieve receiving the flight data from onboard system.

4.5 Summary of Ground Display Design

In this section, the whole process on how to achieve the display design of Ground Station is given out. There are three major parts for the display software design: the display functions design, display data management and data communication. The advanced Human Machine Interface design tool named

VAPS and C code development environment are applied for the design of Ground Station Display System.

5 FMS Ground Control Panel Design

The flight management system is a very complicated system and it is often grouped together with autopilot system. However, for the low-cost vehicle, the flight management is comparatively simple and commonly carried by the Ground Station Computer. It is narrowed down to input the waypoints of path planning in the Ground Station and provide a Graphic User Interface (Ground Control Panel) for trajectory generation and smoothing.

5.1 System Architecture

The main objective of Flight Management System of Ground Station is to provide an efficient human machine interface to facilitate interaction. Through the flight management control panel, operator can input the waypoints, generate the trajectory and smooth the trajectory and so on.

The FMS design mainly includes two modules: the GUIs Module and Algorithm Module. On base of these two parts, the design of flight management system has applied the top-down design architecture. Top-down analyse method is achieved by decomposition. Top-down design is a level-oriented design approach and starts with a top-level description of a system [26]. The process of top-down analyse method is to decompose requirements from higher-level to lower level, until the functions can be specifically designed. The application of top-down analyse design method can reduce the extent of each module and focus on crucial parts. Top-down design method for FMS development is illustrated in Figure 5-1. It is divided into 3 levels. The Flight Management System design (Level 0) is decomposed into a two-module framework including the Graphic User Interfaces module and the Program module in Level 1. GUI module in Level 1 is then continued to be fulfilled by different objects in Level 2 such as Button, Table, Plot and so on. Meanwhile, the Program module in Level 1 is achieved by different Call back Functions in Level 2.

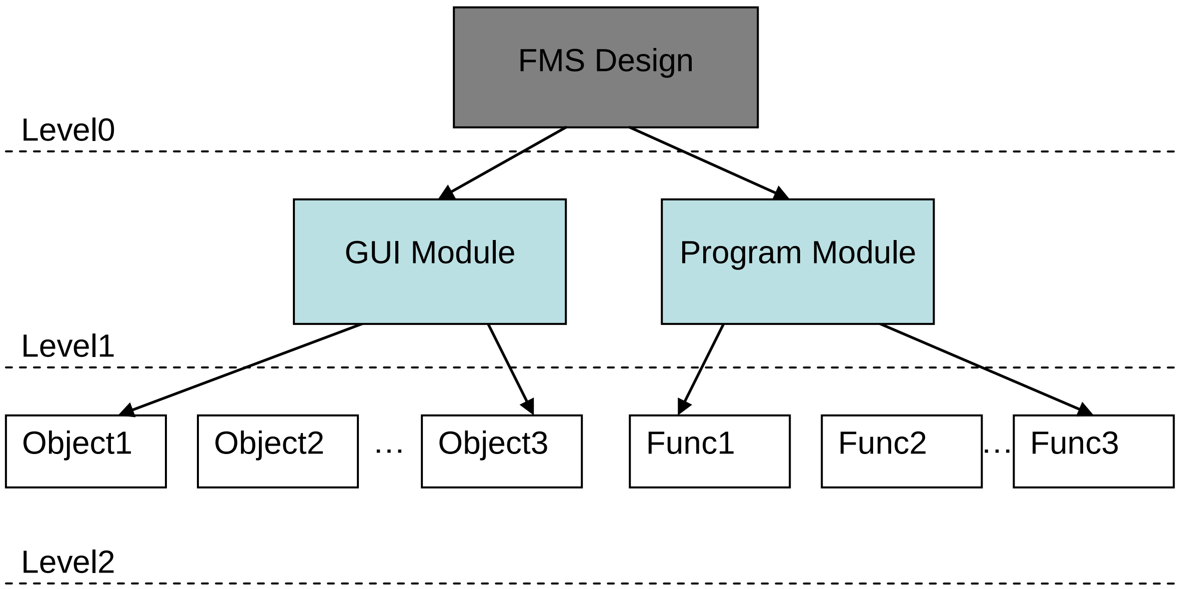


Figure 5-1 Top-down architecture of FMS development

Based on this top-town architecture, the following sections will give out more details on how to achieve the software design of GUI module and Program module in MATLAB development environment.

5.2 GUIs Module Design

GUIs Module Design also applied the object-oriented design method. The MATLAB Graphical User Interface Development Environment (GUIDE) can provide a set of tools for developing graphical user interfaces based on object-oriented design, so it is applied to design the Graphic User Interface Layer for Flight Management System software development. GUIDE Layout Editor (see Figure 5-2) provides a series of GUI components such as buttons, panels, sliders, menus, text fields, and so on. By clicking and dragging these components into Layout Area can design a GUI very easily and quickly.

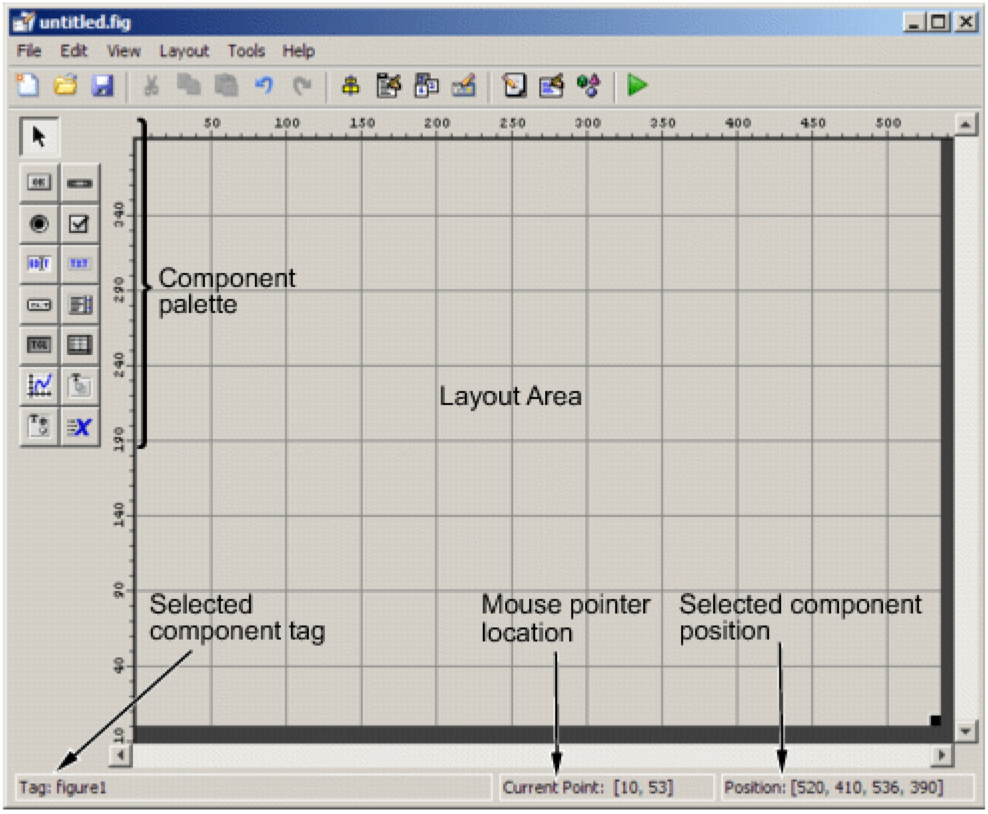


Figure 5-2 GUIDE Layout Editor

Using GUIDE, a Layout for FMS GUI is achieved (see Figure 5-3) which includes four main parts:

1. Three buttons are designed for inputting different plans (PLAN1, PLAN2 or PLAN3) in the top of panel.

2. A Waypoint Editable Table is designed to change the parameters of input plan in the middle of panel.

3. Four buttons are applied for Waypoints Creation, Trajectory Generation, Trajectory Smooth and Clear Plans in the bottom of Control Panel.

4. A display window is designed for displaying the Planned Waypoints, straight-line flight path and smooth flight path in the window.

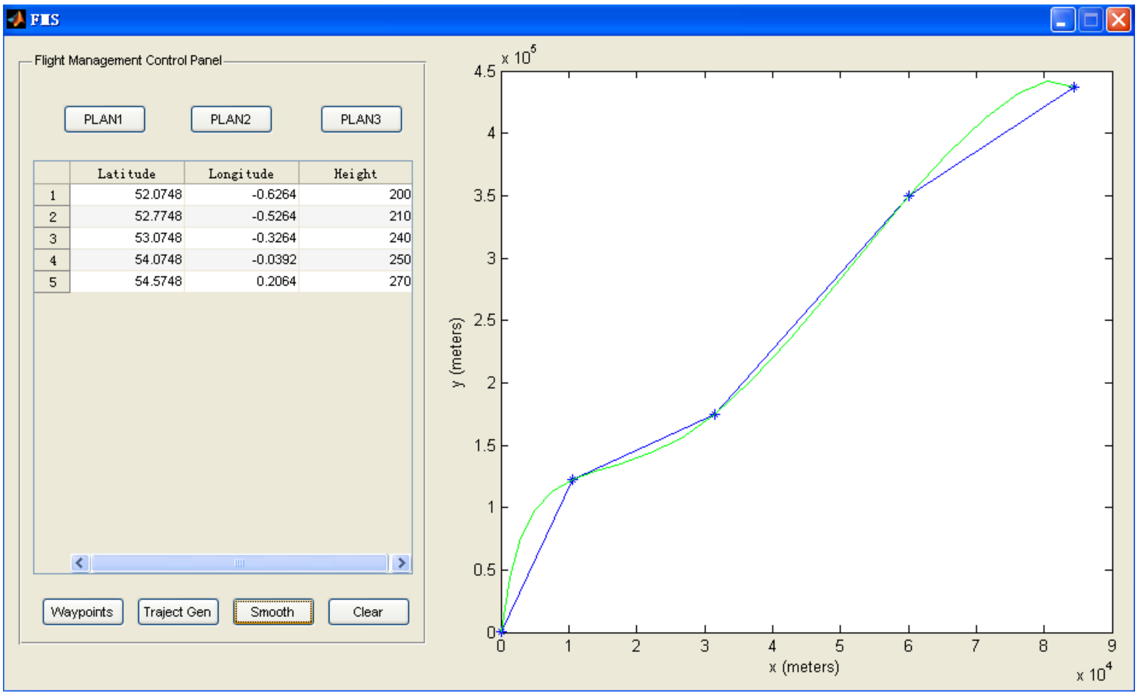


Figure 5-3 FMS Layout Design

Through the control panel, the operator can automatically add three different plans by clicking the different buttons. Operator also can input and change the latitude, longitude and height value of waypoints in the editable table by manual. Finally the flight path is drawn out in the display window. The blue line is the straight path trajectory produced by the input waypoints and the green curve is the trajectory after smoothing.

5.3 Program Module Design

The program module design is to manipulate the behaviour of each object.

GUIDE can automatically generate a MATLAB program file (.m file) which controls the GUIs operation. The call back functions in .m file define the relative commands when user clicks a GUI component. The .m file can be edited in the MATLAB editor, so the code can be added to the call back function to perform the manipulation for the components.

The major functions of FMS control panel is shown in Figure 5-4.

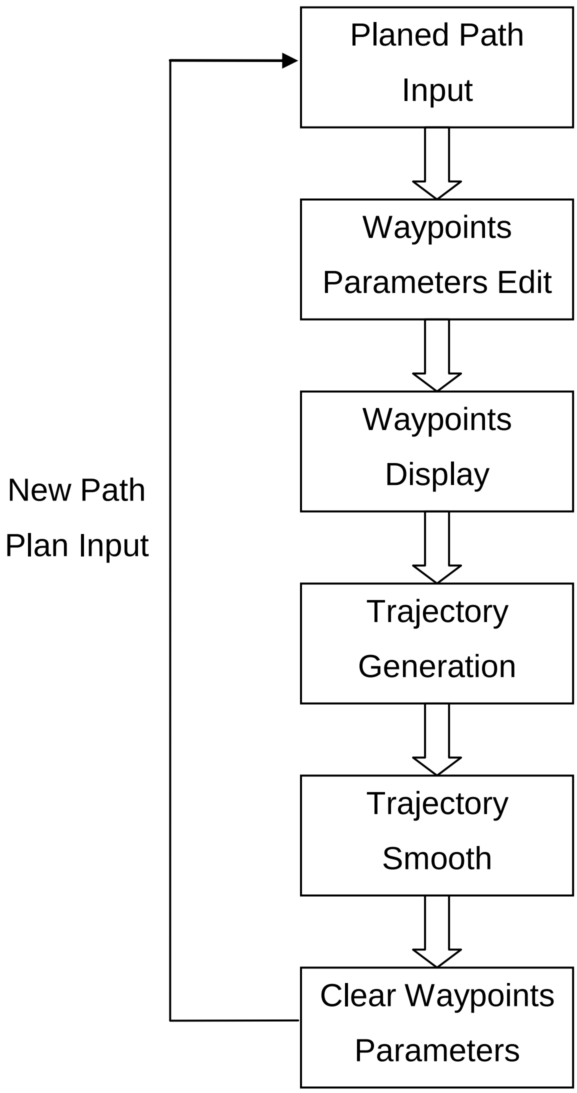


Figure 5-4 FMS Control Panel Functions

1. The call back function of pushbutton 'PLAN'

   This function can add default waypoints value for certain plan (PLAN1, PLAN2 or PLAN3) into the edit table.

2. The call back function of 'Waypoints Table'

   This function can edit the data in waypoints table to change the latitude, longitude and height value of waypoints.

3. The call back function of pushbutton 'Waypoint'

This function can display the input waypoints in the display window for the aircraft.

4. The call back function of pushbutton 'Trajectory Generation'

   This function can plot the chart of waypoints and give out the straight flight path in the display window.

5. The call back function of pushbutton 'Trajectory Smooth'

   This function can smooth the planned flight path and generate new smooth curve in the display window.

6. The call back function of pushbutton 'Clear'

   This function can clear the current planned flight path and ready for a new path plan input.

5.3.1 Trajectory Generation

A crucial part for the trajectory generation display on ground station is to transform the geodetic latitude, longitude, and altitude into flat Earth position.

First of all, some important coordinate concepts are presented as follows [34]:

1. Geodetic coordinates

In geodetic coordinates, it is described in terms of latitude, longitude and height for the position on the earth. The reference ellipsoid is used to define the latitude, longitude and height as Figure 5-5 shows.

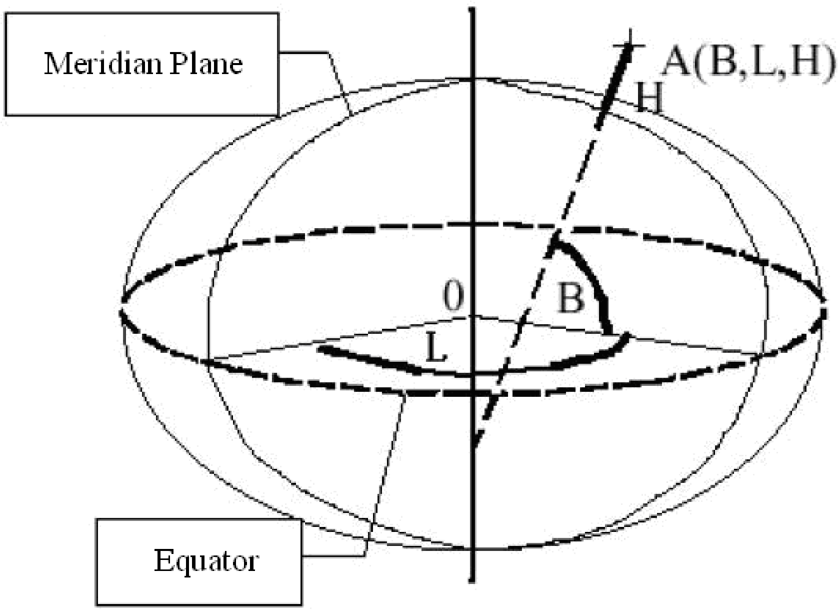


Figure 5-5 Geodetic Coordinates

In this graph, the geodetic coordinate is described by the Meridian Plane and Equator. The major parameters are:

A: Coordinates expression of one point on the earth.

B: Latitude which is the angle between the equator plane and referent point line vertical to reference ellipsoid.

L: Longitude which is angle from meridian plane to the referent point plane perpendicular to equator.

H: Height which is the distance from current point to center of reference ellipsoid.

2. Earth Centered Earth Fixed and East North UP coordinates

ECEF coordinates define three dimensional positions according the center of mass of the reference ellipsoid. The ENU coordinates are applied for the aircraft due to more intuitive and practical.

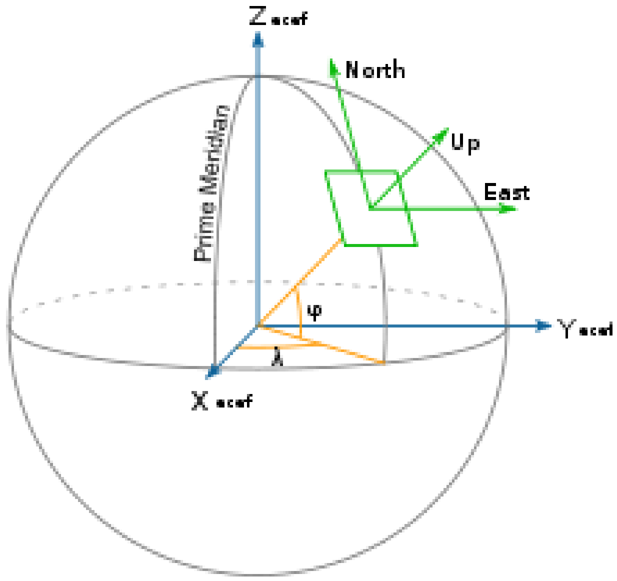


Figure 5-6 Earth Centred Earth Fixed and East, North, Up coordinates

Earth Centred Earth Fixed and East North Up coordinates are presented in Figure 5-6. The ECEF coordinates are three dimensional including X, Y and Z axes with the origin at the center of earth as the blue lines show. ENU coordinate is created from a tangent plane to the Earth's surface as the green lines show.

3. projection coordinates

For the display of aircraft position, input parameters of waypoints might not explicitly describe locations with geographic coordinates (latitudes, longitudes and heights). Therefore, the parameters must be transformed to plane coordinates (This is also called projection coordinates).

Generally, map projections are classified as cylindrical, conical and azimuthal projections. The Cylindrical Projection is applied for the ground station development.

A cylindrical projection [35] is produced by wrapping a cylinder around a globe representing the Earth. Figure 5-7 shows a regular cylindrical projection which is tangent to the earth surface along the equator. Projection method is shown on the left and the projection example is give out on the right.

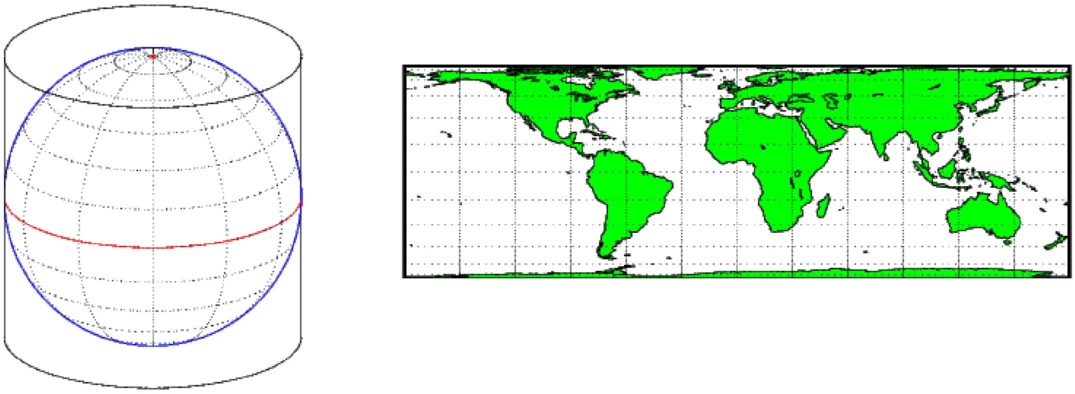


Figure 5-7 Cylindrical Projection [35]

The Mercator projection is one of cylindrical map projection which is put forward by the Flemish (Belgian) and cartographer Gerardus Mercator in 1569.

The following equations give out how to transform the coordinates of one point from its latitude φ and longitude λ (the centre of map is shown by λ_0) to the x (east forward axis) and y (north forward axis) coordinates of a point on a Mercator map.

$$
\begin{aligned}
x &= \lambda - \lambda_0 \\
y &= \ln\left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right) \\
&= \frac{1}{2}\ln\left(\frac{1+\sin(\varphi)}{1-\sin(\varphi)}\right) \\
&= \sinh^{-1}\left(\tan(\varphi)\right) \\
&= \tanh^{-1}\left(\sin(\varphi)\right) \\
&= \ln\left(\tan(\varphi) + \sec(\varphi)\right).
\end{aligned}
$$

According to this mathematics, mapping toolbox in MATLAB is applied to achieve the coordinate transformation in this thesis because it can provide tools and utilities for analyzing geographic data and creating map displays.

5.3.2 Trajectory Smooth

The cubic spline interpolation method is applied to smooth the straight-line flight path. Cubic spline interpolation is a powerful data analysis method which can verify data efficiently. The process of cubic spline interpolation is as follows [36]:

$$S(x) = \begin{cases} s_1(x) & \text{if} \quad x_1 \le x < x_2 \\ s_2(x) & \text{if} \quad x_2 \le x < x_3 \\ & \vdots \\ s_{n-1}(x) & \text{if} \quad x_{n-1} \le x < x_n \end{cases} \tag{1}$$

Where s_i is a third degree polynomial which is defined by

$$s_i(x) = a_i(x - x_i)^3 + b_i(x - x_i)^2 + c_i(x - x_i) + d_i \tag{2}$$

Where for i = 1, 2, ..., n-1.

The first and second derivatives of these n-1 equations are fundamental to this process, and they are

$$s_i^{\prime}(x) = 3a_i(x - x_i)^2 + 2b_i(x - x_i) + c_i \tag{3}$$

$$s_i^{\prime\prime}(x) = 6a_i(x - x_i) + 2b_i \tag{4}$$

Where for i = 1, 2, ..., n-1.

Based on this theory, the interp1 command in MATLAB is used to interpolate between the waypoints. It finds values at average of points. This interpolate method is shown in Figure 5-8 by using vectors x, Y, xi, and yi.

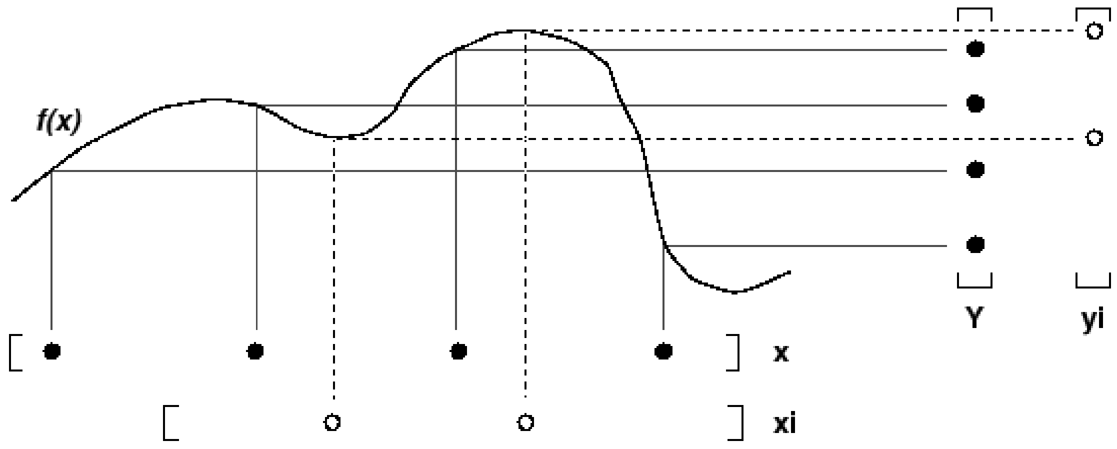


Figure 5-8 Cubic Spline Interpolation [31]

Using this method, the curve can be obtained continuously and appeared smooth from the straight-lined path. The Figure 5-9 shows a trajectory smoothing result after cubic spline interpolation.

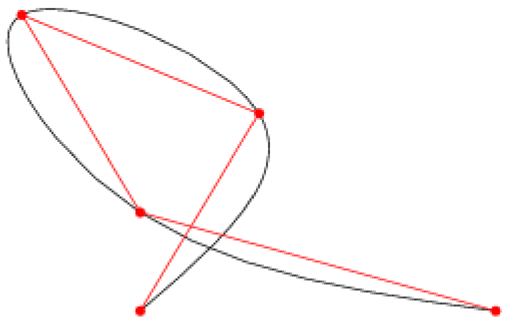


Figure 5-9 Trajectory Smoothing Result

5.4 Summary of FMS Ground Control Panel Design

In this section, the Flight Management Development Control Panel for Ground Station is accomplished in MATLAB software development environment.

Through the FMS Control Panel, the operator can complete the control and display of the input of waypoints, trajectory generation and trajectory smooth to guide aircraft flying.

6 Simulation and Result

6.1 Ground Display Simulation

The stimulation channel can be used to provide data to consumer plugs to test objects' behaviours during the development process. This channel contains built-in periodic and ramp functions to drive output objects.

The periodic members (Sine, Cosine, Triangular, and Square) use single precision arithmetic and cycle at 1, 0.1, and 0.01 Hz.

The ramp members begin counting at 0 and increase perpetually, one unit at a time, at a rate of 10 units per second.

The Stimulation channel is a read-only channel with 13 plugs. Table 6-1 shows the functionality of these plugs:

Table 6-1 Functionality of Simulation Channel

FUNCTION	FREQUENCY			
	1,2...	1 Hz	0.1 Hz	0.01 Hz
Sine	No	Yes	Yes	Yes
Cosine	No	Yes	Yes	Yes
Triangular	No	Yes	Yes	Yes
Square	No	Yes	Yes	Yes
Ramp	Yes	No	No	No

After connecting these simulation channel members to the consumer plug of display objects, the display impact can be tested at runtime. Some examples of simulation and implement results are shown as follows.

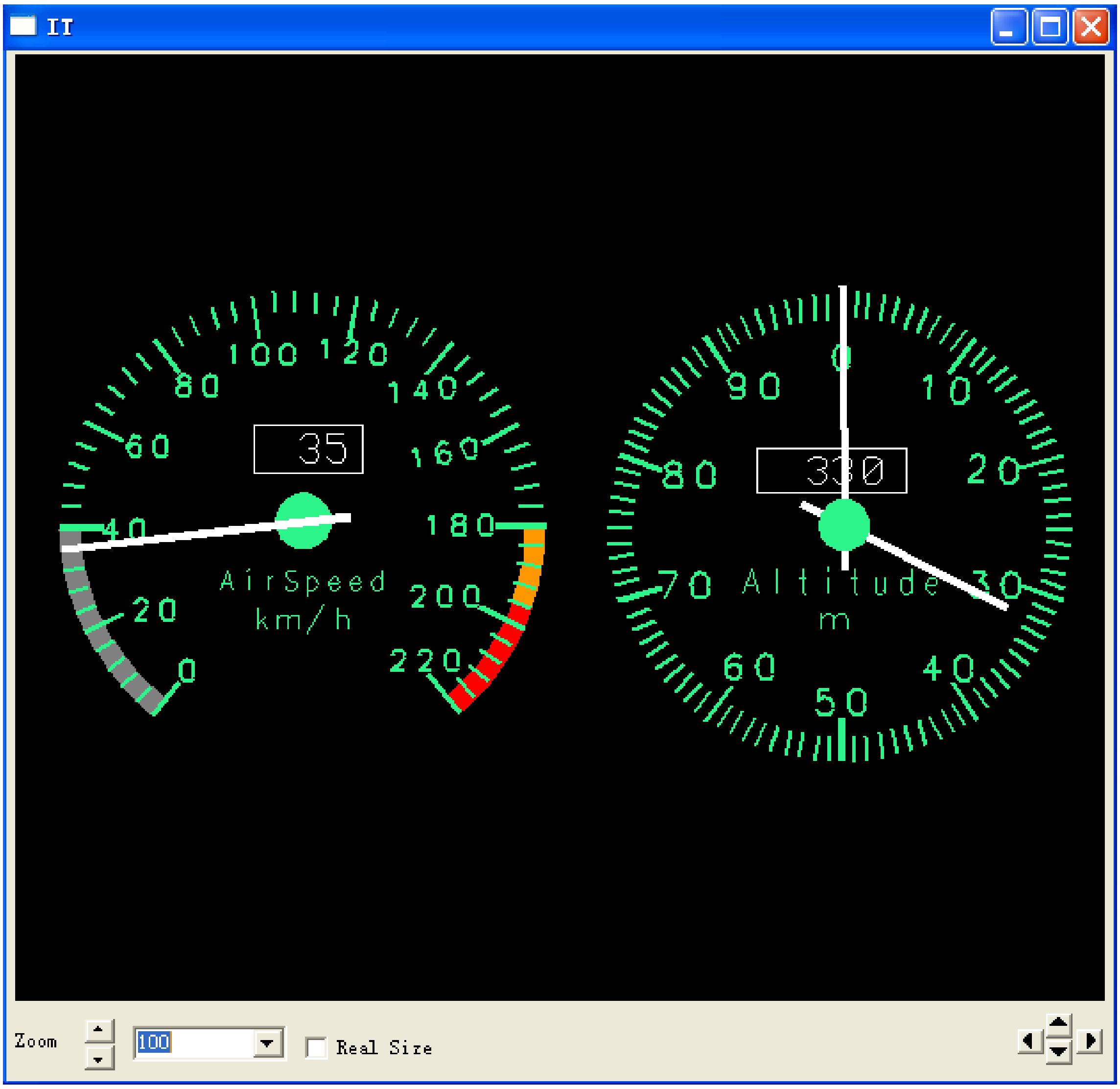


Figure 6-1 Simulation Result for Airspeed Display

This display result in Figure 6-1 presents the simulation results of airspeed and altitude including digital value and table value using the ramp member.

The ADI object simulation result in the primary flight display is given out by Figure 6-2.

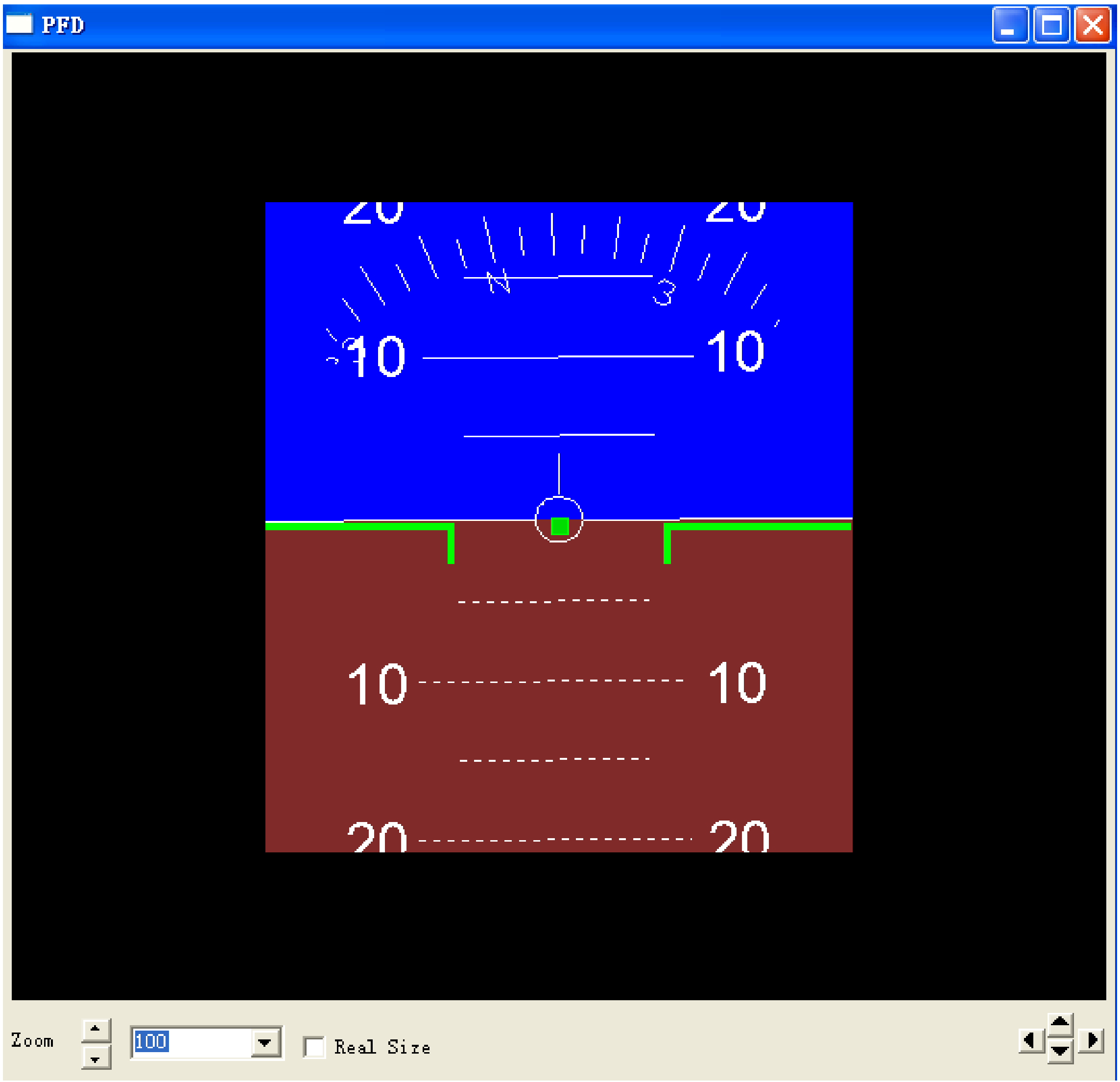


Figure 6-2 Simulation Result for ADI

In this display frame, it includes the simulation and implements results for heading, pitch and roll of aircraft. The heading simulation used the ramp member, the pitch used the cosine periodic member with cycle at 0.1Hz and the roll used the sine periodic member with cycle at 0.1Hz.

Finally, an integrated, intuitive and easy operative Human Machine Interface is achieved for ground station. The ground station display simulation and implement result is shown in Figure 6-3.

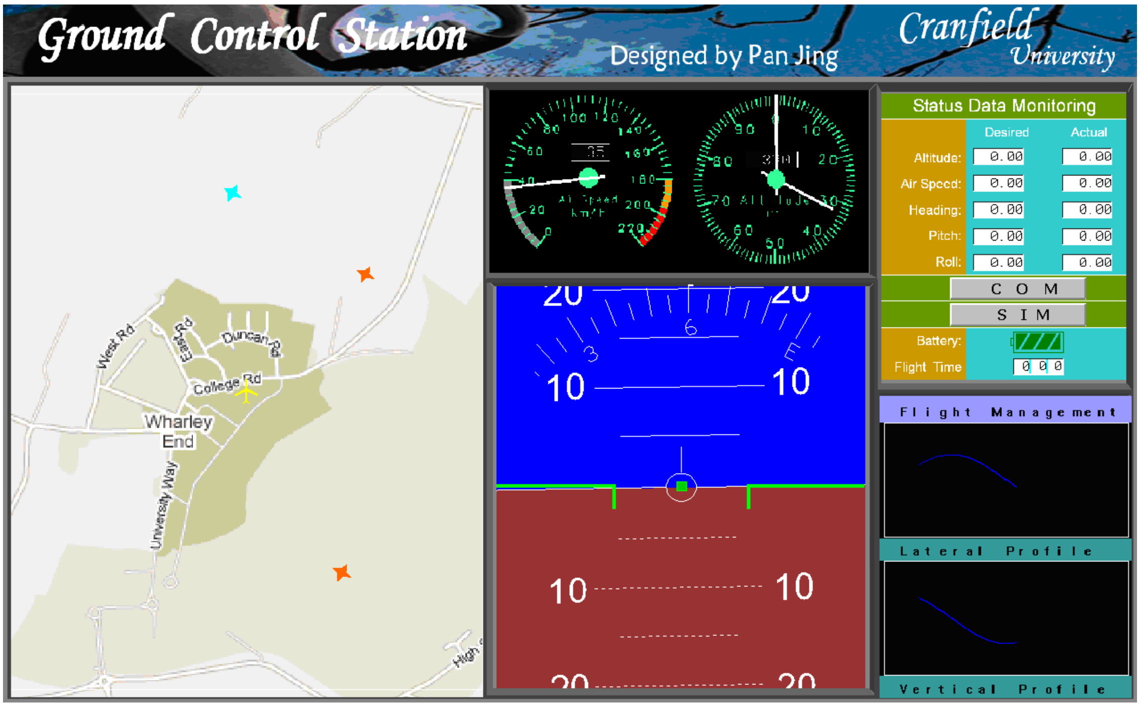


Figure 6-3 Ground Station Display Simulation and Implement

The display of ground station is mainly divided into four zones:

1. Instrument Display Zone: including the altitude, air-speed and attitude (pitch, roll and heading). It is located in the centre of display. In the upper centre, the airspeed and altitude are displayed. The Attitude Director Indicator (ADI) is in the lower centre.

2. Navigation Display Zone: including the active map, waypoints and the aircraft. It is located in the left of the display.

3. Status Monitoring Zone: including status data monitoring, communication status, battery monitoring and flight time display. It is displayed in the upper right.

4. Flight Management Display Zone: including the lateral and vertical flight profile.

The simulation result demonstrates that the ground station display can provide a friendly HMI for monitoring the flight data such as the position, airspeed, altitude, heading, pitch, roll, system status and flight profile.

6.2 FMS Control Panel Simulation

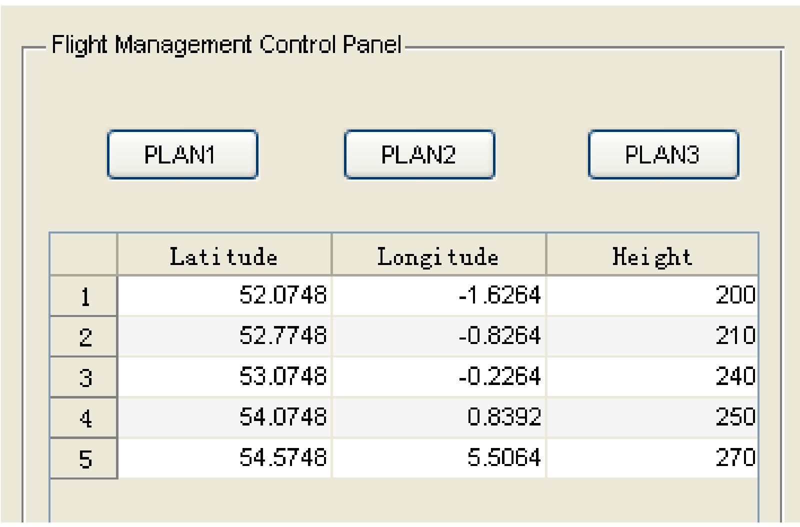
Trajectory smoothing is a very important and but complex part of a flight management. It is required to transform a piece-wise straight-line trajectory to a time-stamped and kinematically feasible trajectory that can be followed by the vehicles.

In order to test the smoothing component of the flight management system control panel, three example path plans are simulated. These test the operation of the component and demonstrate how waypoint parameters is loaded, and edited and how the smoothing operation is performed.

It should be noted that the smoothing operations shown in this thesis are for example only and are not intended to provide realistic trajectories – that is outside of the scope of this work. Hence the simulation is only for testing the operation process of human machine interface for flight management, not the true trajectory for guiding the aircraft flight.

1. Trajectory simulation for path plan1.

Trajectory1 simulates a single direction flight path including five waypoints. The simulation results of Trajectory1 are shown in Figure 6-4, Figure 6-5, Figure 6-6 and Figure 6-7.



	Latitude	Longitude	Height
1	52.0748	-1.6264	200
2	52.7748	-0.8264	210
3	53.0748	-0.2264	240
4	54.0748	0.8392	250
5	54.5748	5.5064	270

Figure 6-4 Parameters of Waypoints for Trajectory1

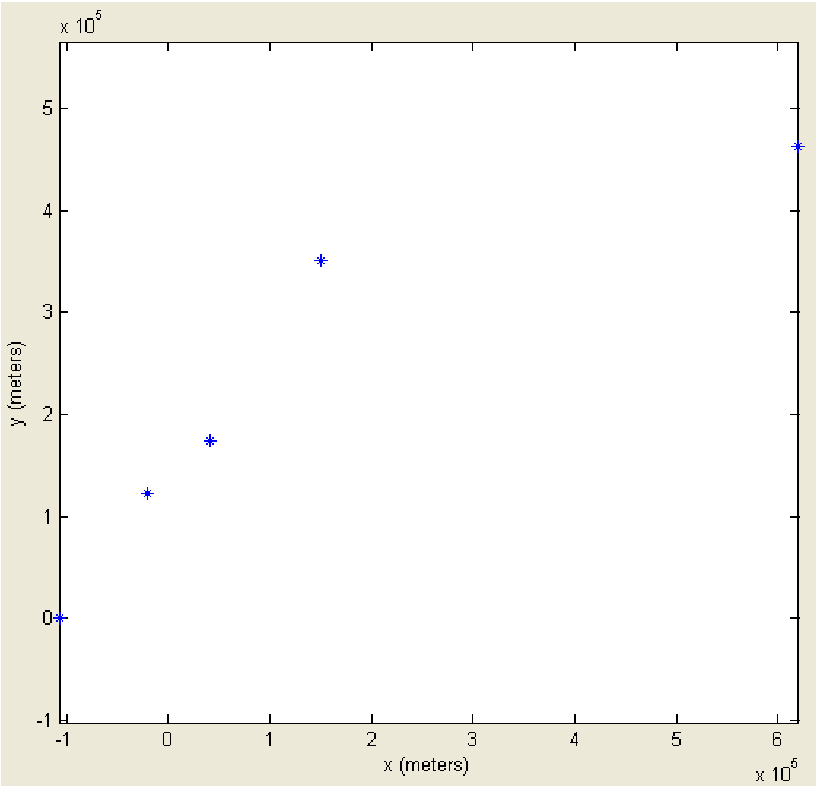


Figure 6-5 Waypoints Result for Trajectory1 on Plane Coordinate

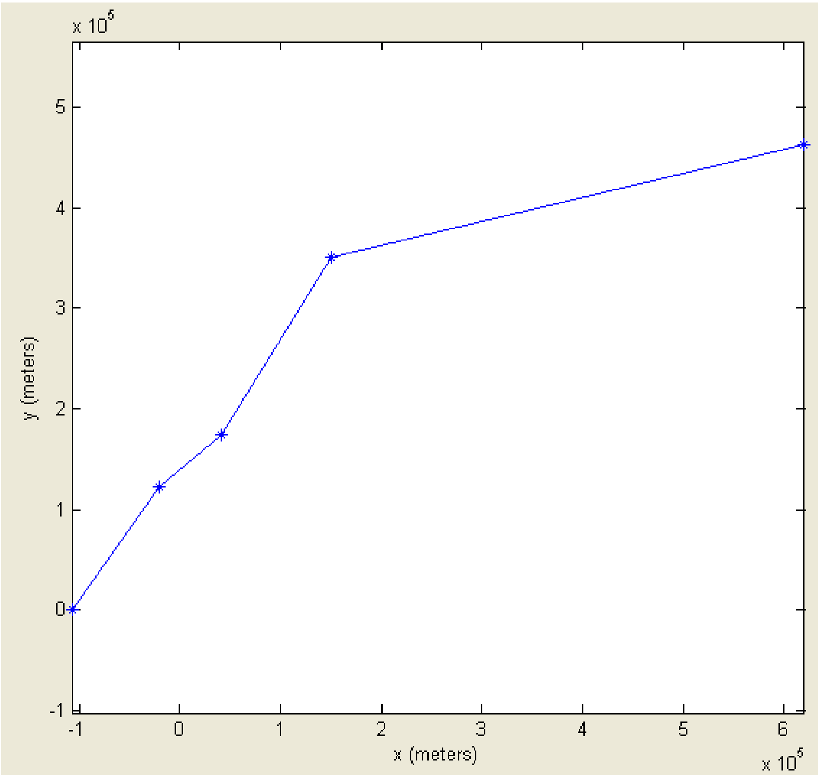


Figure 6-6 Trajectory1 Generation Result on Plane Coordinate

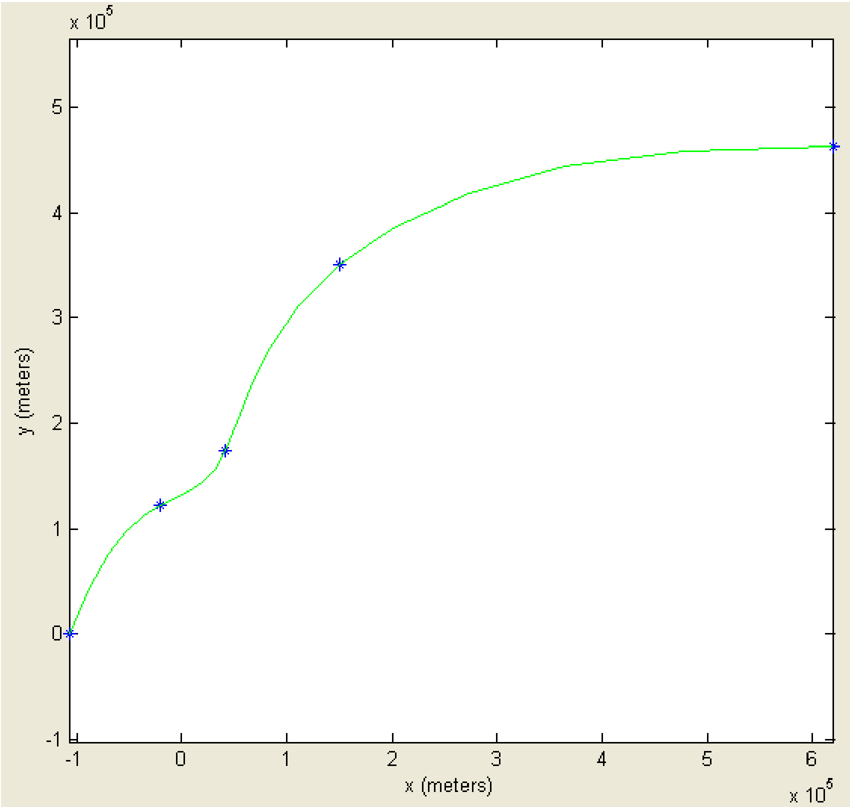
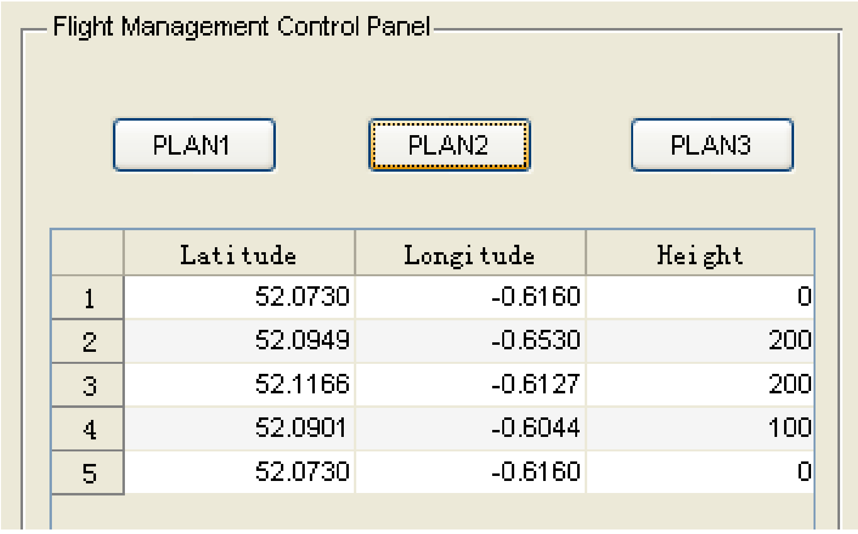


Figure 6-7 Trajectory1 Smooth Result on Plane Coordinate

2. Trajectory simulation for path plan2.

Trajectory2 simulates a loop flight path including five waypoints. The simulation results are shown in Figure 6-8, Figure 6-9, Figure 6-10 and Figure 6-11.



	Latitude	Longitude	Height
1	52.0730	-0.6160	0
2	52.0949	-0.6530	200
3	52.1166	-0.6127	200
4	52.0901	-0.6044	100
5	52.0730	-0.6160	0

Figure 6-8 Parameters of Waypoints for Trajectory2

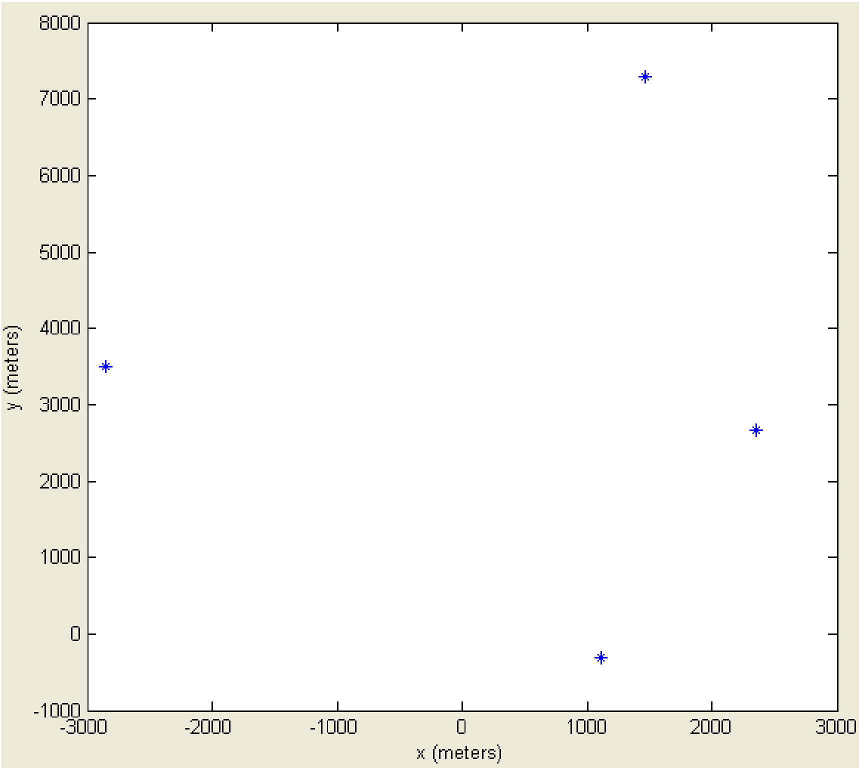


Figure 6-9 Waypoints Result for Trajectory2 on Plane Coordinate

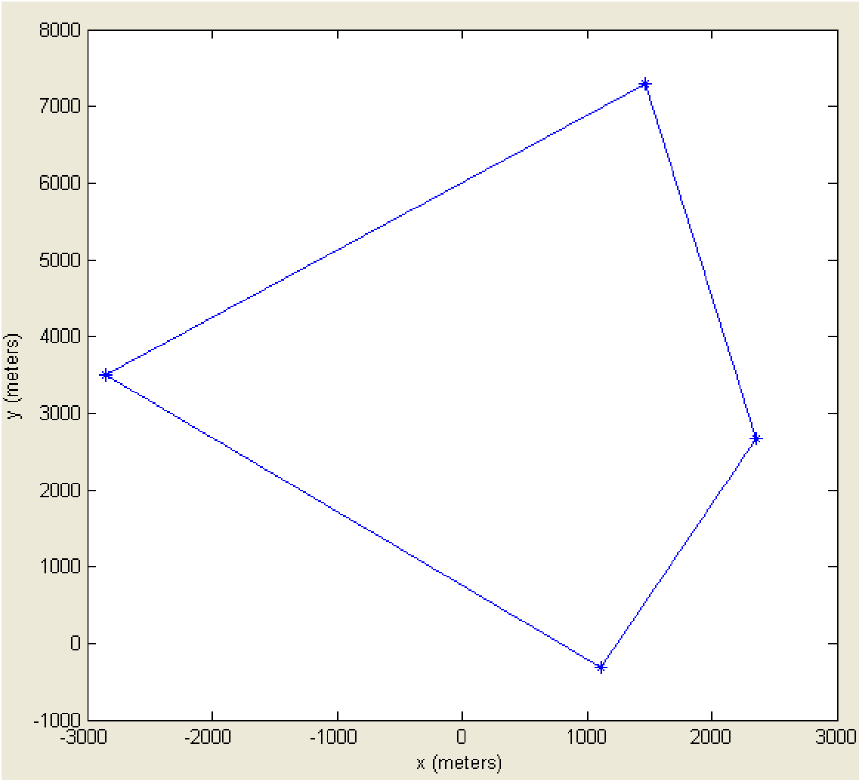


Figure 6-10 Trajectory2 Generation Result on Plane Coordinate

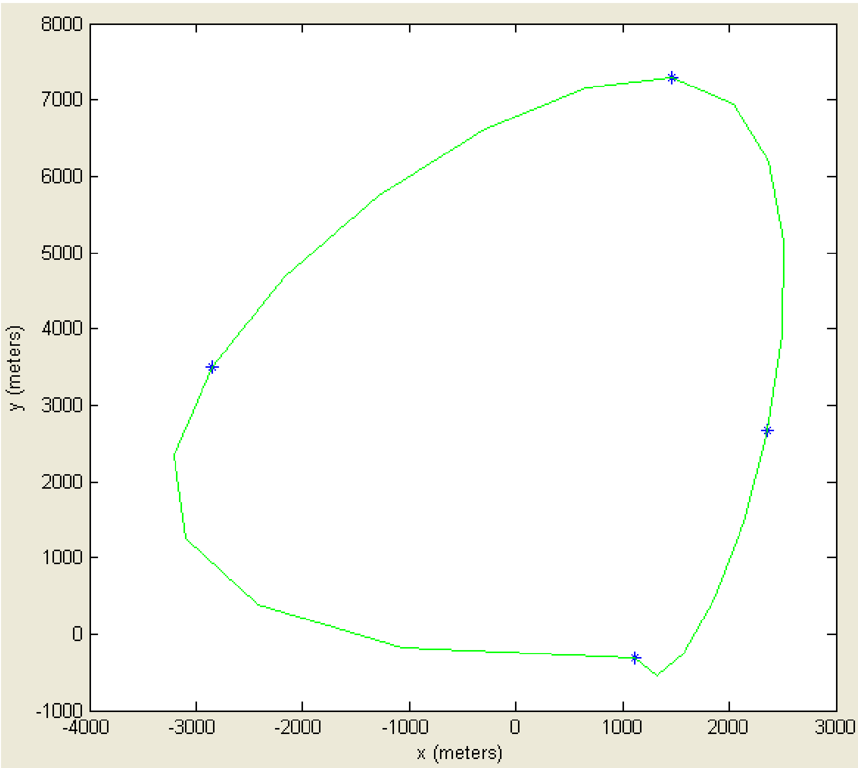
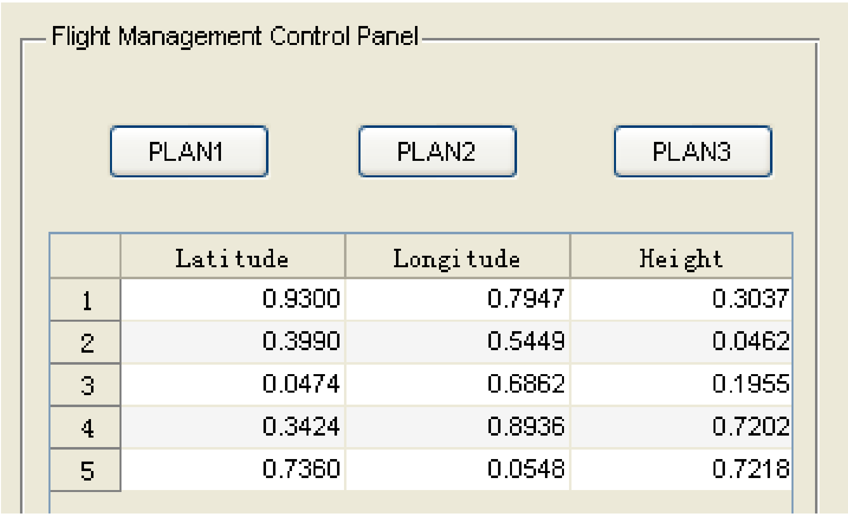


Figure 6-11 Trajectory2 Smooth Result on Plane Coordinate

3. Trajectory simulation for path plan3.

Trajectory3 simulates a randomly generated flight path with five waypoints. The simulation results of Trajectory3 are shown in Figure 6-12, Figure 6-13, Figure 6-14 and Figure 6-15.



	Latitude	Longitude	Height
1	0.9300	0.7947	0.3037
2	0.3990	0.5449	0.0462
3	0.0474	0.6862	0.1955
4	0.3424	0.8936	0.7202
5	0.7360	0.0548	0.7218

Figure 6-12 Parameters of Waypoints for Trajectory3

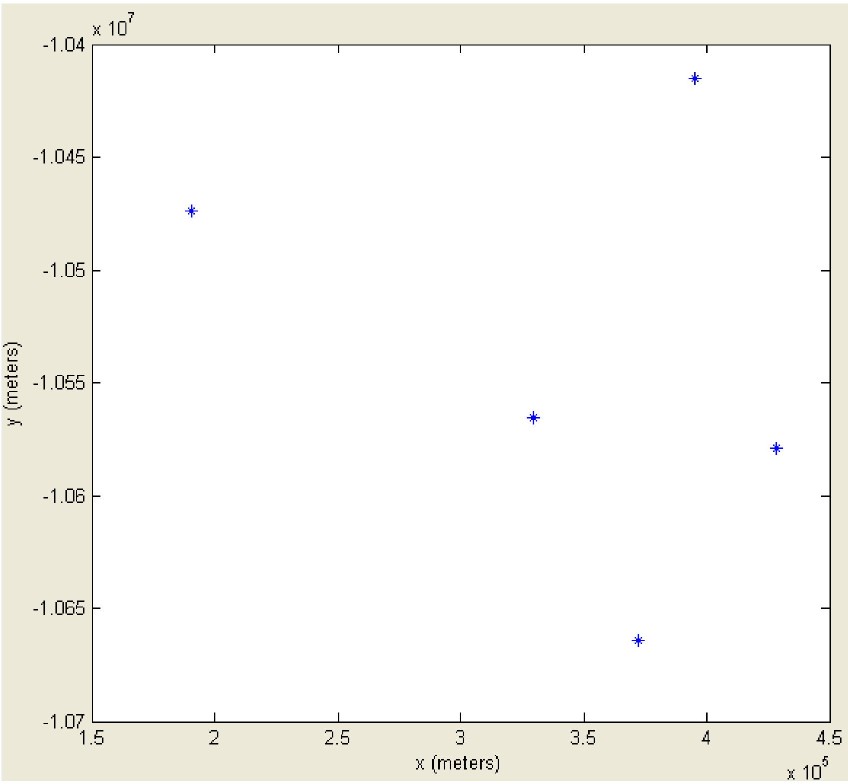


Figure 6-13 Waypoints Result for Trajectory3 on Plane Coordinate

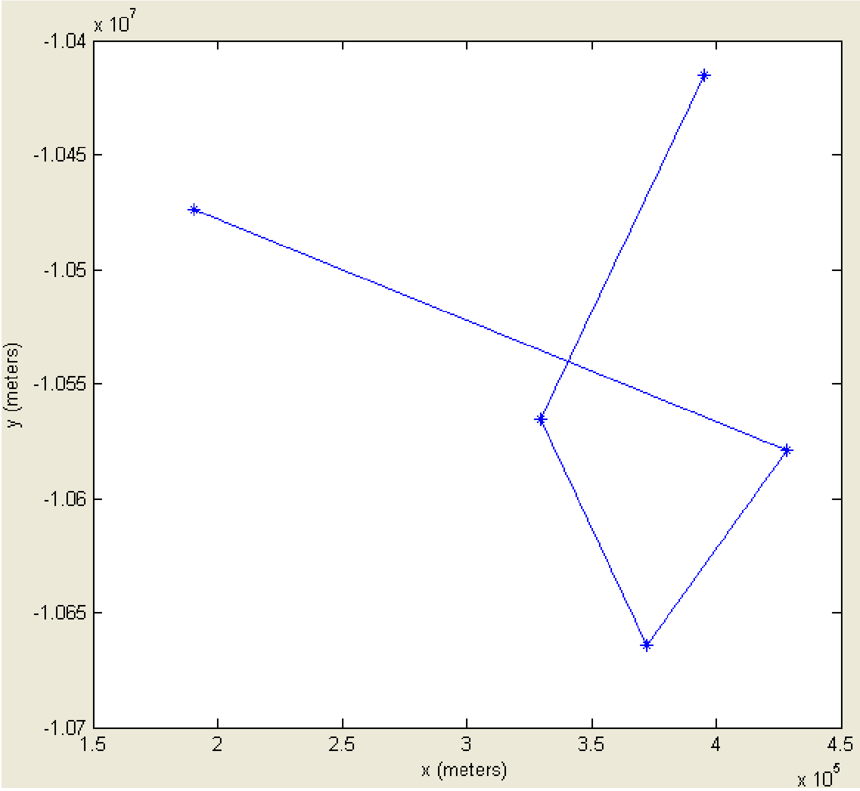


Figure 6-14 Trajectory3 Generation Result on Plane Coordinate

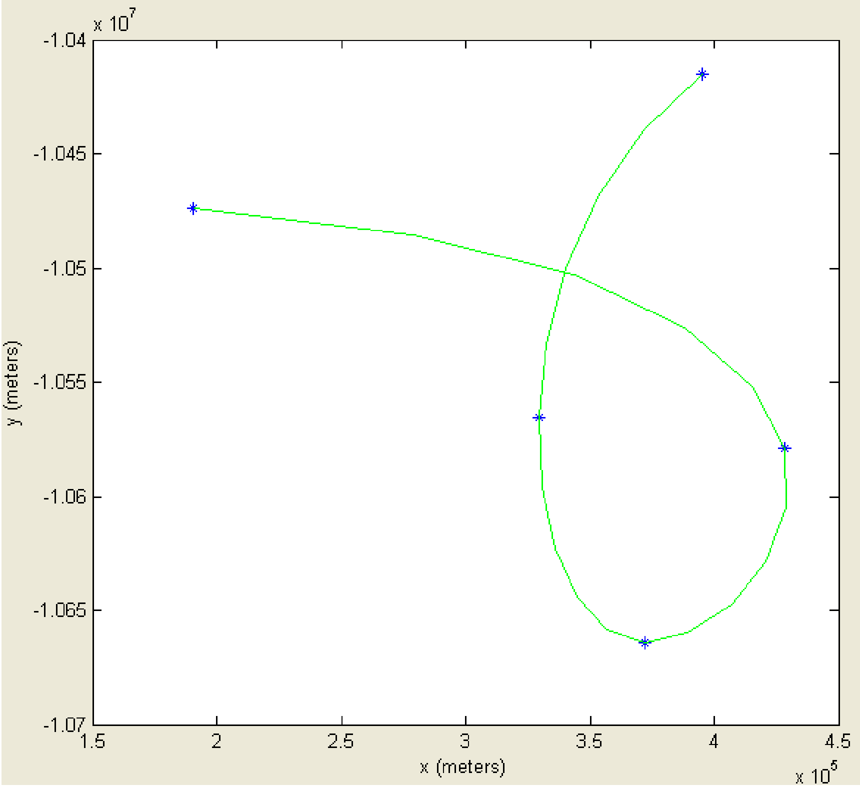


Figure 6-15 Trajectory3 Smooth Result on Plane Coordinate

6.3 Summary of Simulation

In this section, simulation is carried out for ground station display and FMS control panel.

Firstly, some simulation data are connected to all of display objects to drive the movement via the simulation channel to test the behaviour and impact of ground station display.

Secondly, three trajectories are simulated for the control of flight path planning in FMS control panel.

The simulation and implement results indicate both the display and FMS control panel of ground station can provide intuitive and easy operative HMIs and reduce operator workload.

7 Conclusion and Future Work

7.1 Conclusion

The ground station is an essential part for low-cost vehicle to provide controlling and monitoring the vehicle. To fulfill the aim, a ground station on base of laptop including a display Human Machine Interface and a Graphic User Interface for the Flight Management System has been achieved.

The development of Ground Station for Low-Cost Vehicle is based on the VAPS and MATLAB software which are chosen due to the advantages of Object-Oriented and Rapid Prototype design methods.

To achieve an intuitive and easy operative Human Machine Interface, VAPS software is applied to display and monitor the real-time flight status of air vehicle.

Meanwhile, a Graphic User Interface for the Flight Management System is also developed for the Ground Station. The MATLAB development tool (including GUI and M files) is applied to implement the waypoints input and the flight plan for the vehicles.

Comparing with the traditional code programming, the application of these COTS tools will be much easier and quicker.

At the end of IRP, the software system has been thoroughly tested through the simulation in the computer. Moreover, the software developed in this project is flexible and can be also used to other vehicle system with minimal data interfaces modifications.

7.2 Recommendation for Future Work

Owing to the limitation of time, some further work can be done for the ground station in the future:

1. The network communication test between onboard and ground station

The communication test between onboard and ground systems hasn't been performed till to now. The data requirement for display has been presented, but more network interface such as the data message formats should be verified in the next step.

2. Air Traffic Control for Multi-vehicles

The avoidance of collision is a crucial problem for modern UAVs which requires the ground station to provide a clear display for multi-vehicles to operator. It needs to collect and display some flight data of all vehicles in a certain zone such as position, altitude, airspeed, heading and so on. Therefore, some information from onboard sensors such as radar and data links needs to be integrated to ground station system.

3. Real-Time Camera Vision Display

In this thesis, a static map display is merged in to show the aircraft position relative to the waypoints, flight path and the location in a certain terrain. More work could be done to achieve the display of onboard camera vision and provide a real-time map vision for the operator on the ground station.

4. Voice Interface

With the development of speech recognition technology, the remote control for the aircraft via voice interface on ground can come into reality. Therefore, in the future, the voice interface could be added to provide a more simple and quick interface for the operator on the ground station.

5. Trajectory Smoothing

Futher work needs to be done on the trajectory smoothing methods to include advanced methods that take account of the vehicle constraints and which maintain the (near) optimality of the flight path.

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APPENDICES

Appendix A Introduction to Group Design Project

A.1 Introduction to GDP

The project is to design a 130 seat passenger aircraft aimed at both Chinese domestic and global market with delivery in 2020 namely the Flying Crane.

The conceptual and preliminary design of this project had performed by the 1st and 2nd cohort AVIC students in their GDP in 2008/09 and 2009/2010 respectively.

The objective of this year's Group Design Project will be in the detailed design stage of 130-Seat Civil Aircraft Flying Crane following in the result of conceptual and preliminary design.

A.2 Task Allocation

Design of two avionics subsystems:

1. Flight Deck – Cockpit Control and Displays System.

   The work for flight deck – cockpit control and displays system are as follows:

   - Analyze Cockpit control and display function and safety requirements
   - Overall cockpit control and display architecture design
   - Definition of display contents, format and symbols, display units design
   - Primary flight displays
   - Multifunction displays
   - Highway/tunnel-in-the-sky displays, including airport taxi guidance, etc.
   - Displays of avionics system and other aircraft system health status

- Determine display equipment and evaluate their performance
- Display systems simulation
- Safety assessment
- Integration of display systems into aircraft and some display software systems into Net-ASS

2. Enhanced Vision System.

   The work for enhanced vision system (EVS) is as follows:

   - Analyse the functional and safety requirements of enhanced vision system, including definition of all-weather and all-environmental conditions
   - Design and develop functional and physical EVS architectures
   - Analyse and determine required EVS sensors and their performances, including EVS
   - Develop EVS algorithms and software architecture
   - Simulation and evaluation of EVS algorithms
   - Integration of EVS into aircraft
   - Safety assessment

Appendix B   Cockpit Control and Displays System

The flight deck of an aircraft contains flight instruments on an instrument panel, and the controls which enable the pilot to fly the aircraft. The objective of cockpit control and displays System is to combine all of the airborne information, the strengths and limitations of the pilots, processing pattern of human brain to make the display characteristics clear, unambiguous and intuitive as long as easy operative.

The detailed design of flight deck – cockpit control and displays system started with the results of the preliminary design last year. It mainly contains the definitions and requirements, system performance, data collection, system architectures, display layout and PSSF analysis on cockpit control and displays system.

B.1   Validation of Preliminary Design

B.1.1   The layout of cockpit

The layout of cockpit in preliminary design is showed in Appendix Figure B-1. It is mainly composed of control panels and six AMLCDs. In this phase，Head-Up Display (HUD) is designed as an optional instrument for customers based on the place and cost concerns. However, to fulfil the requirement of AWAE, that is all weather all environments, HUD would be a better choice in the cockpit control and display system. Using HUD equipment to display the SVS or EVS data will minimize the transition from heads down to the out-of-the-window scan. With the development of technology and cost decline, HUDs have been more and more widely applied in civil aircraft and they are essential to improve the situational awareness ability, especially for takeoff and landing phase. So, considering different requirements of different customers, three typical versions are offered for Flying Crane:

1. No Head-up Display

In this version, there is no Head-up Display and enhanced vision system, then synthetic vision is provided by the head-down display – integrated primary flight display to achieve the enhanced situational awareness.

2. One Head-up Display

In this version, only one Head-up Display is provided for the captain.

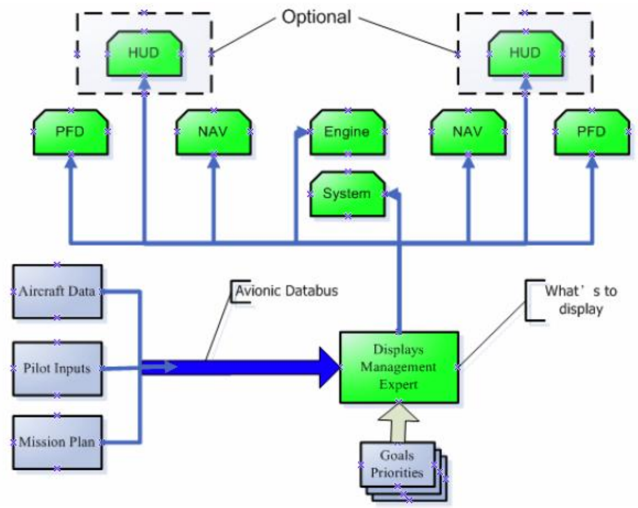
3. Two Head-up Displays

In this version, each Head-up Display is provided for the captain and first officer.

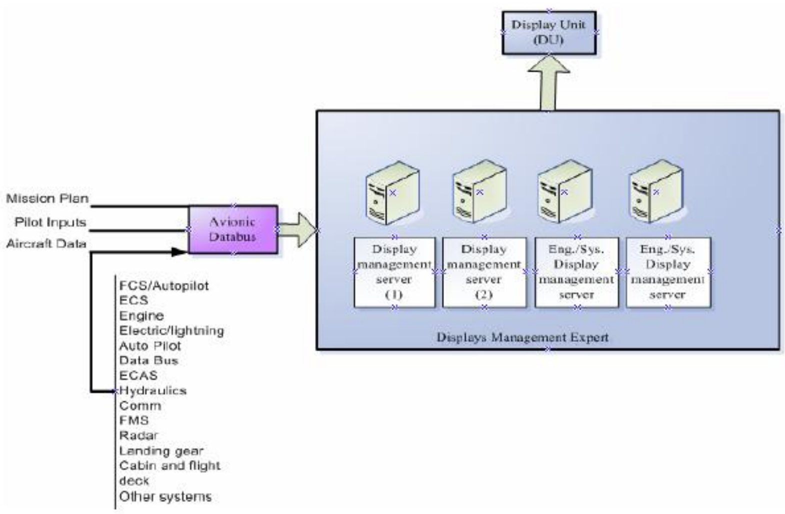
Appendix Figure B-1 Layout of cockpit in preliminary design

B.1.2 The architecture of display system

The architecture of display system in preliminary design is showed in Appendix Figure B-2. The Display Management Expert (DME) is used to process all of data for display which is illustrated by Appendix Figure B-3.

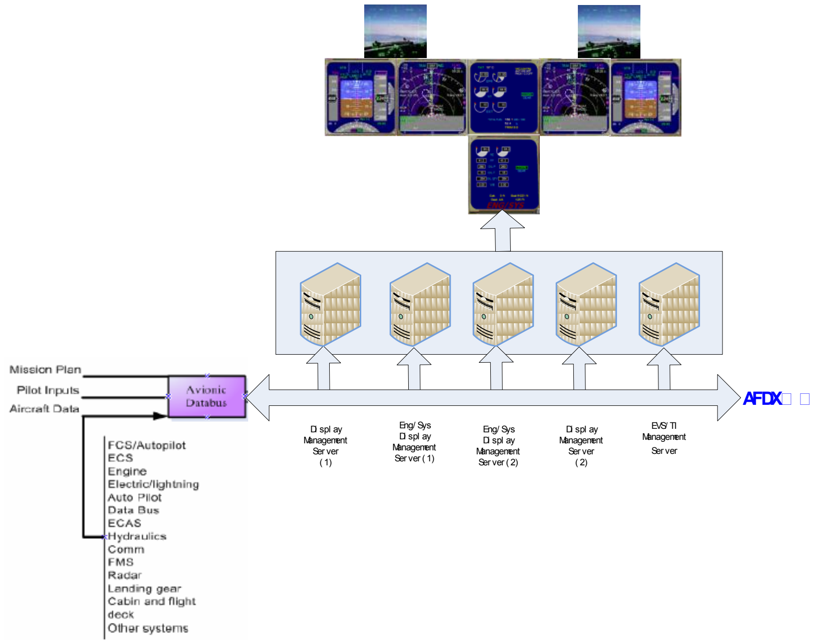


Appendix Figure B-2 Architecture of display system in preliminary design



Appendix Figure B-3 Display Management Expert

Detailed design improved the architecture of display system illustrated as Appendix Figure B-4 The display system is connected with other systems via AFDX (Avionics Full Duplex network) and transmits data with all the monitors through Digital Visual Interface（DVI）. Compared with the preliminary design, it has five servers by adding one for EVS/terrain information and audio-visual warning management.



Appendix Figure B-4 Improved Architecture of Display System in Detailed Design

B.2 Allocation of Requirements and Interface

B.2.1 Allocation Of Requirements

In practice, the allocations of hardware and software requirements are tightly-coupled, processes.

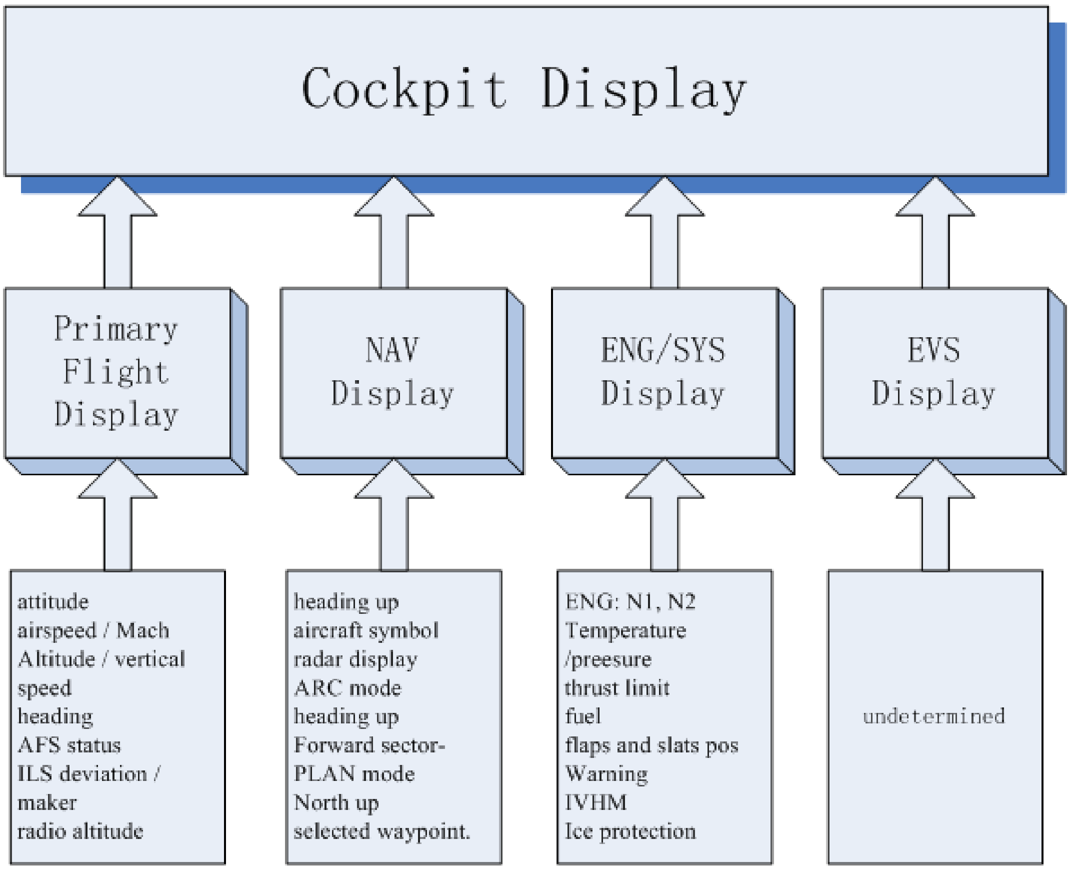
Flight deck instruments/displays can be mainly categorized into three types:

1. Primary flight instruments providing information on the ability of the aircraft to sustain safe and controlled flight.

2. Navigation instruments providing information about the aircraft position with respect to its surroundings in order for the aircraft to be safely directed from its point of origin to its destination.

3. Engine instruments and systems providing information about the aircraft systems to assure the continual safe function of the aircraft for the duration of the intended flight.

To achieve the functions, relevant data requirements should be allocate to these display instruments. Appendix Figure B-5 illustrates the requirements allocation of these display instruments.



Appendix Figure B-5 Requirements Allocation Diagram

1. Primary Flight Display (PFD)

Primary flight displays are the outer displays on captain and first officer panel, they provide information on:

- Heading and track
- Barometric and radio altitude and vertical speed
- Air-speed
- Attitude and guidance command

- Flight mode annunciations
- Vertical and lateral derivations

2. Navigation Display (ND)

Navigation displays are the inboard displays on captain and first officer panel. The NDs present all information for navigation the aircraft, including flight plan route display, moving map of database navigation aid/waypoints/airports, navigation aid bearing pointers and information, TCAS (Traffic Alert and Collision Avoidance System) display, etc.

3. Engine/Warning Display(E/WD)

Engine/Warning Display (E/WD) is the upper of two Electronic Centralized Aircraft Monitoring (ECAM) display. It is organized in two areas, the Engine display and Warning display.

4. System Display(SD)

System Display (SD), the lower of ECAM display, has multiple pages dedicated to different aircraft system. The pages include: BLEED, PRESS, ELEC, HYD, ENGINE, FUEL, APU, COND, DOOR/OXY, WHEEL, F/CTL and CRUISE.

B.2.2 Interface

Before the system hardware and software design, the interface issue should be solved between the display system and other subsystems. After coordinating with other guys, the Interface of Display System is illustrated in Appendix Table B-1.

Appendix Table B-1 Interface of Display System

Cockpit Displays	Data discribe	Data update rate	resource
Aircraft reference (boresight) symbol	The position of aircraft symbol	20ms	Navigation system
Pitch	scale and horizon relative to boresight	20ms	Navigation system
Roll	scale and horizon relative to boresight	20ms	Navigation system
Heading	Horizon, HSI and digital readout	20ms	Navigation system
Speeds	CAS(tape),vertical speed, ground speed, speed error tape	20ms	Navigation system
Altitudes	Baro altitude (tape), digital radio altitude	20ms	Navigation system
Navigation data	ILS, VOR, DME, maker beacons	20ms	Navigation system
Flight path	The route of flight	20ms	FMS
Flight path acceleration	arrival time （TOT）	20ms	FMS
Slip/skid indicators	DEGEE	20ms	FMS
FGS Flight director(F/D) guidance cue and modes	MAP,VOR,APPROACH	20ms	FMS
Flight director armed and capture modes		20ms	FMS
Wind Speed and direction		20ms	FMS
Selected parameters	Selected altitude	20ms	FMS
	Selected altitude	20ms	FMS
	Selected Airspeed	20ms	FMS
	Selected Course	20ms	FMS
Trajectory prediction		20ms	FMS
Selected and current track		20ms	FMS
Selected and current heading		20ms	FMS
Waypoint		20ms	FMS
Next waypoint distance		20ms	FMS

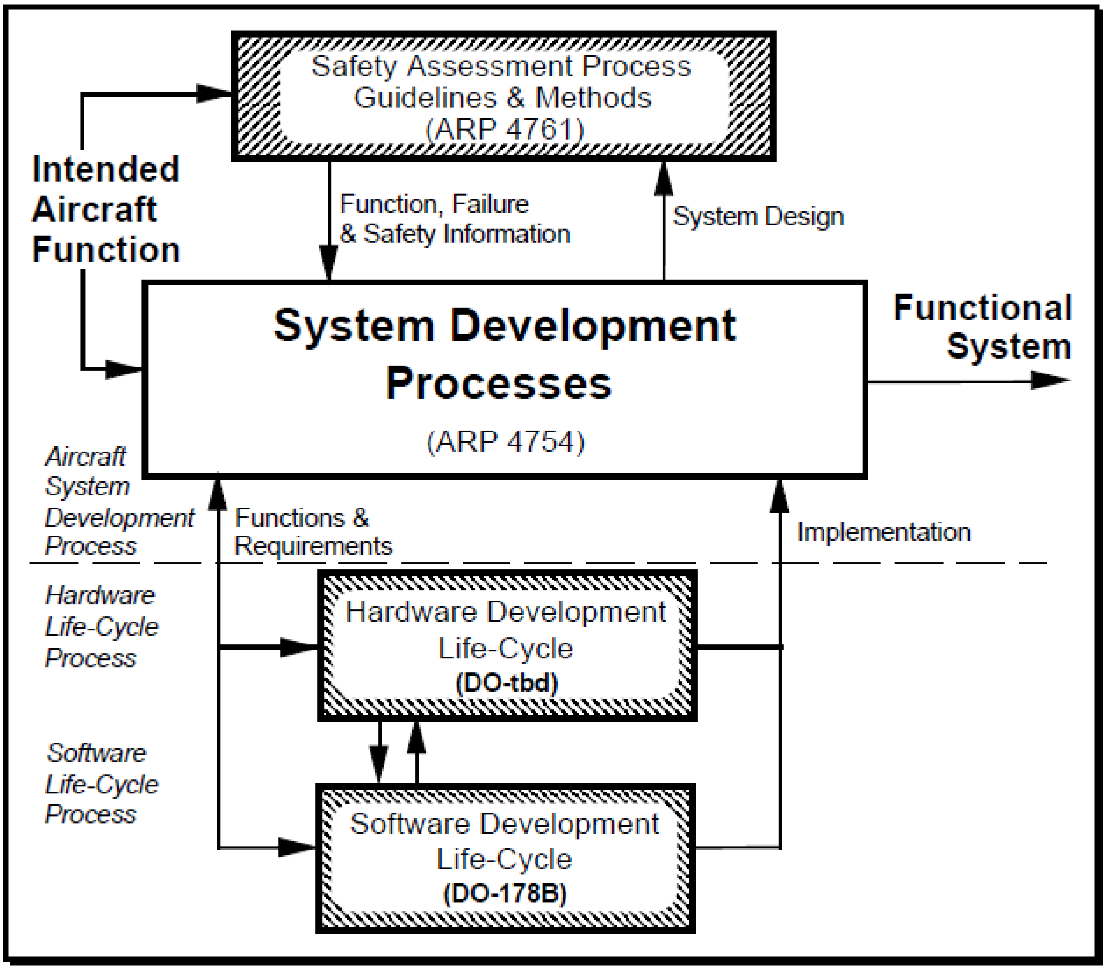
Cockpit Displays	Data discribe	Data update rate	resource
Waypoint estimated time of arrival		20ms	FMS
Range to selected altitude		20ms	FMS
Selected navigation data points		20ms	FMS
EPR	Engine Pressure Ratio	20ms	Engine system
EGT	Exhaust Gas Temperature	20ms	Engine system
N1	LP Rotor speed, in%	20ms	Engine system
N2	HP Rotor speed, in%	20ms	Engine system
Thrust limit	Thrust limit mode	20ms	Engine system
FF	Fuel flow per engine, in current units	20ms	Fuel system
FOB	Total fuel onboard, in current units	20ms	Fuel system
Warning display	Warning and advisory	20ms	GPWS,Weather RDR,TCAS

B.3 System Hardware and Software Design

B.3.1 Certification Of Hardware and Software Design

According to ARP 4754, the hardware and software design/build processes should provide traceability to the requirements allocated to hardware and software for each item. Appendix Figure B-6 illustrates the certification guidance documents covering system, safety, hardware and software processes. Hardware and software design process is referred to DO254 and DO178B. RTCA/DO-254 provides design assurance guidelines for developing airborne electronic hardware. This is a very important design guidance document for digital avionics, and it consists of a detailed summary of best practices by the engineering organizations from international aviation manufacturers. Its intention is to provide this guidance for the development of airborne electronic hardware such that it safely performs its intended function in its specified environments.

RTCA/DO-178B presents the guidelines which are specifically oriented to ensure levels of software performance consistent with achieving flight safety at an agreed upon level. So far, in order to satisfy the certification requirement, the hardware design is developed from the perspective of international. However, with the technology progress of avionics in china, the national choice will be a trend from the cost and self-reliance concerned. Therefore，a new version based on the national hardware design should be launched later.



Appendix Figure B-6 certification guidance documents covering system, safety, hardware and software processes

B.3.2 Hardware Decision and performance

1. Head-Down Display

Honeywell's D-size (8"x 8") colour LCDs are chosen as the "flat panel" liquid crystal display in Flying Crane's cockpit control and display system. These displays provide significant performance advantages as well as reduced life cycle cost. The characteristics of chosen LCDs are shown as Appendix Table B-2.

Whether driven by a VIA or AIMS computer, the Honeywell Colour LCDs provide the benefits – larger display area, better contrast in high sunlight conditions and enhanced display resolution that make it a highly desirable component on the flight deck.

Appendix Table B-2 Characteristics of chosen LCDs

Size (H x W x D)	8.26 in. x 8.37 in. x 10.65 in.
Weight	14 pounds
Power	28 VDC 120 Watts (heaters off) 270 Watts (heaters on)
MTBF	29,000 flight hours
Hardware Qualification	DO-160D
I/O	Digital Video bus (4) NTSC video (1)
Viewable area	6.7 in. x 6.7 in.
Resolution	1152 x 1152
Brightness	0.05 to 100 fL (2000:1 dimming range)
Viewing angle	+/- 55 deg Horiz; +30/-10 deg Vert

2. Head-Up Display

Digital Head-up Displays of Thales Avionics are chosen by Flying Crane. The D-HUDS can offer complete standard flight instrumentation and guidance in all phases of flight. Moreover, it can be enhanced with better graphics quality, visual image and a new generation of EVS/SVS /SGS capability. The technical data of DHUD is shown in Appendix Table B-3.

Appendix Table B-3 Technical Data of DHUD

- Weight: 23 kg
- Power Consumption: 160 w
- A 764 compliant
- Environment: DO 160 D
- Software Category: DO 178 B level A
- Contrast: 1.2 (symbology and video)
- Brightness: 10,000 Cd/m2
- Maintenance:
  - No scheduled maintenance
  - BITE – Self Test
  - Modular design for optimal maintenability

HPU/HCU

- Field Of View: 35° x 26°
- Resolution: SXGA
- LCD glass from Thales LCD
- Auto/Manual brightness adjustment for symbols and video
- Auto/Manual Declutter

HUDC

- Size: Arinc 600 - 6 MCU
- Power Supply: 115V/400Hz
- I/O:
  - A429 – AFDX
  - Digital Video XGA
  - RS 422 – RS 232
  - Discretes

3. ISIS

Comparing to the preliminary design, the standby instruments are developed into Integrated Standby Instrument System (ISIS) in detailed design. The ISIS can provide an independent display of attitude, mach, altitude, airspeed and vertical speed. The ISIS in Smith Aerospace is chose in Flying Crane. The Characteristics are showed in Appendix Table B-4.

Appendix Table B-4 Characteristics of ISIS

Weight: 1.7 kg
Dimensions: 3ATI
Power: 28 V DC, 12 W
Brightness Range: 2000:1
Reliability: >15,000 h MTBF
Useable Screen Area: 61 × 61 mm
Sensors: Solid-state rate sensors, accelerometers and pressure transducers
Interfaces: Pneumatic connections for Pitot and Static, external brightness control (option), ARINC 429 (4 receive/2 transmit channels), 12 discrete inputs
Qualification: DO-160C
Software: DO-178B
Certification: TSO C2d airspeed, C3d turn and slip, C4c bank and pitch, C10b altimeter, C113 airborne multipurpose electronic displays, C34e ILS glideslope receiving equipment, C36e ILS localiser receiving equipment, C95 machmeters, C8d vertical speed (planned)

B.3.3 System Software Design

During the software design of cockpit display, federal aviation administration advisory circular 25-11 is referred as the display format guidelines.

The advisory circular, FAA AC 25-11 encapsulates perceived wisdom for the design and certification of electronic display systems. The document is advisory rather than mandatory, but it does provide guidance and outlines methods for complying with the regulatory requirements. The advisory circular provides specific display data integrity guidelines (see Appendix Table B-5). It recommends that:

1. The display should convey information in a simple uncluttered manner. Colour alone should not be used as a discriminator. Symbols or messages should be logically and consistently positioned and co-located with associated information.

2. That careful attention should be given to symbol priority to assure easy interpretation of three-dimensional information on a two-dimensional medium.

3. Display contexts should be clear, intuitive and not dependent on training or adaptation for correct interpretation.

4. The .basic T. relationship should be followed. If side-by-side formats are used, then attitude, airspeed, altitude, and heading must still reside in the .basic T arrangement.

5. Heading and attitude must be presented on the same display.

6. Altitude and airspeed should be arranged so that the present value is located as close as possible to a horizontal line extending from the centre of the attitude indicator.

The advisory circular cautions about the compelling nature of the map display and notes that there have been incidents where gross map position errors have gone undetected or unbelievable because the flight crew have falsely relied on the map instead of correct raw data. It reinforces the need for operating procedures that require one crew member still to monitor raw navigation data.

Appendix Table B-5 Display data integrity guidelines

Parameter	Criticality	Probability of	
		Complete loss	Misleading data*
Engine data	Critical	Extremely improbable	Extremely improbable
Attitude, airspeed, altitude, heading	Critical	All = extremely improbable† Primary = extremely remote‡	Extremely improbable
Navigation, vertical speed, slip/skid crew alerting	Essential	Extremely remote	Extremely remote

The standardized colour coding that is advised to facilitate information discrimination is shown in Appendix Table B-6 and that for weather radar precipitation and turbulence in Appendix Table B-7.

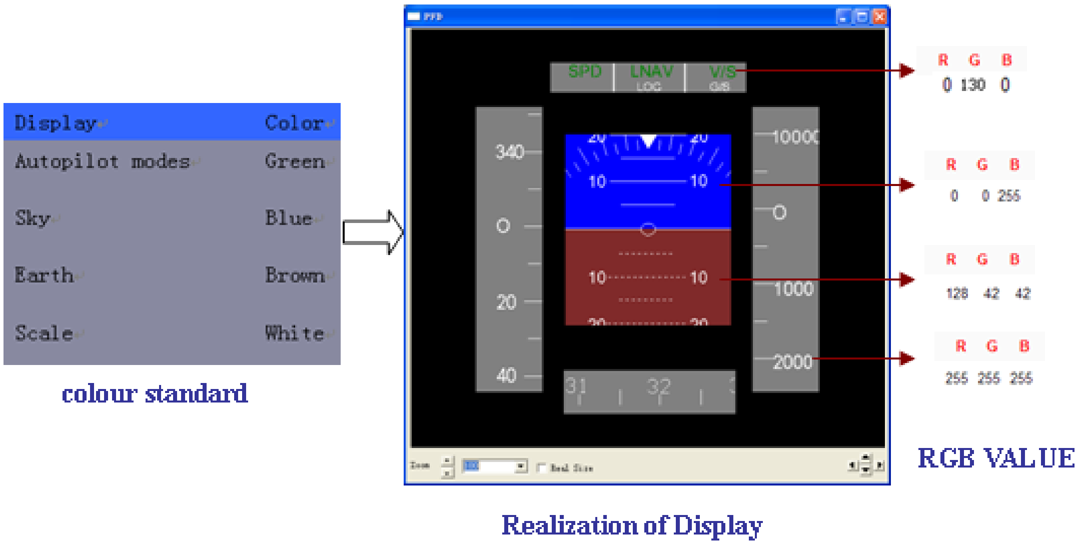
Appendix Table B-6 colour coding to facilitate information discrimination

Warnings	Red
Flight envelope and system limits	Red
Cautions, abnormal sources	Amber
Earth	Tan/brown
Sky	Cyan/blue
Scales and associated figures	White
Flight director/ILS deviation pointer	Magenta/green
Autopilot engaged modes	Green
Fixed reference symbols	White
Current data, values	White or green
Active route plan	Magenta or white

Appendix Table B-7 colour coding for radar precipitation and turbulence

Precipitation (mm/h)	
0 – 1	Black
1 – 4	Green
4 – 12	Amber/yellow
12–50	Red
>50	Magenta
Turbulence	White or magenta

Referring the standards of AC25-11, one page display for Primary Flight Display is designed as Appendix Figure B-7 illustrated.



Appendix Figure B-7 Primary Flight Display Software Display

The left table in the figure is the colour standard in AC25-11, the middle frame is the display realization and the right is the colour RGB value to show how to fulfil the standard. Some typical colour HEX and RGB values are illustrated in Appendix Table B-8.

For examples:

- Autopilot modes is required to be green in the AC25-11, so the RGB VALUE is set as 0:0:255
- Sky display is required to be blue in the AC25-11, so the RGB VALUE is set as 0:0:255
- Earth display is required to be Brown in the AC25-11, so the RGB VALUE is set as 128:42:42
- Scales and associated figures is required to be White in the AC25-11, so the RGB VALUE is set as 255:255:255

Appendix Table B-8 Colour Values

Color Values

Color	Color HEX	Color RGB
	#000000	rgb(0,0,0)
	#FF0000	rgb(255,0,0)
	#00FF00	rgb(0,255,0)
	#0000FF	rgb(0,0,255)
	#FFFF00	rgb(255,255,0)
	#00FFFF	rgb(0,255,255)
	#FF00FF	rgb(255,0,255)
	#C0C0C0	rgb(192,192,192)
	#FFFFFF	rgb(255,255,255)

B.4 System Safety Assessment

B.4.1 Validation of Preliminary Design

The following work has done in preliminary design:

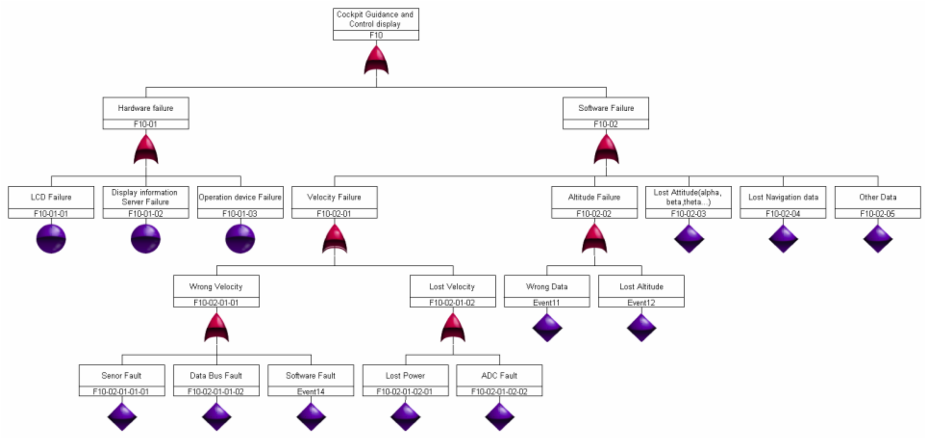
1. A case study of Function hazard assessment of flight deck display system was shown in Appendix Table B-9.

Appendix Table B-9 Functional hazard assessment (FHA) –Case study

Function Ref.	Function Description	Failure Condition Ref.	Failure Condition (Hazard Description)	Flight Phase	Effect on Aircraft/Occupants 1. Aircraft 2. Crew 3. Cabin occupants	Classification	Validation	Verification	Remark
R-10A	pilot-aircraft interface	R-10A-1	Loss Altitude	G1/G2 T1/ F1~F4 /L1	See blow				
		42-1A-1a	Total loss of altitude	L1	1. In very extremely improbability condition 2. The pilot would be in big trouble in controlling the aircraft. 3.Other crew and occupants fast seatbelt.	I			
		42-1A-1b	Total loss of altitude	T1/ F1~F4 /L1	1. Would make the aircraft in a very extreme condition. If not recover, mission should be canceled and search for other help. 2. Flight crew has much difficult to control a/c and go on the mission.. 3. None.	II			
		42-1A-1c	Lost primary altitude		1. In control 2. Increase the pilot load 3. None	III			

Flight Phase				Failure Condition Classification
Ground	Takeoff	In Flight	Landing	
G1 Aircraft Static with System Operating G2 Taxi	T1 Takeoff	F1 Climb F2 Cruise F3 Descent F4 Approach F5 Other (Describe)	L1 Landing	Ⅰ Catastrophic Ⅱ Hazardous Ⅲ Major Ⅳ Minor Ⅴ No Safety Effect

2. Different altitude loss was analyzed as an example. The Fault Tree Analysis was achieved in Appendix Figure B-8.



Appendix Figure B-8 FTA Diagram

3. System Fault Hazard Assessment is listed in the Appendix Table B-10

Appendix Table B-10 FHA Table

Parameter	Criticality	Probability of		comment
		Complete Loss of	Hazardously Misleading Data	
Attitude	Critical	All: Extremely Improbable Primary: Improbable	All: Extremely Improbable Primary: Improbable	
Airspeed	Critical	All: Extremely Improbable Primary: Improbable	All: Extremely Improbable	
Barometric altitude	Critical	All: Extremely Improbable Primary: Improbable	All: Extremely Improbable	
Vertical	Essential	All: Improbable	---	
Rate of Turn	Non-Essential	---	---	
Slip/Skid indicator	Essential	All: Improbable	All: Improbable	
Heading (Stabilized)	Essential	All: Improbable	All: Improbable	Not include the clock and stand by instrument
Navigation	Essential	All: Improbable	All: Improbable	Only concern its display.
Crew Alerting	Essential	All: Improbable	All: Improbable	
Flight Crew Procedures	---	---	improbable	
Weather Radar	Non-essential	---	Probable	

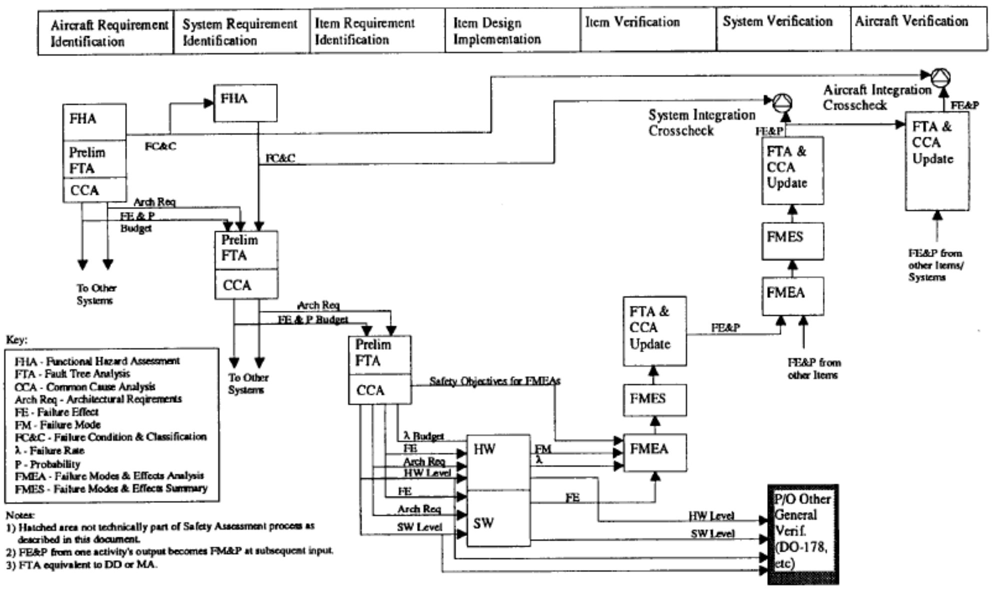
B.4.2 SSAs

The System Safety Assessment (SSA) is a systematic, comprehensive evaluation of implemented system to show that safety objectives from the FHA and derived safety requirements from the PSSA are met.

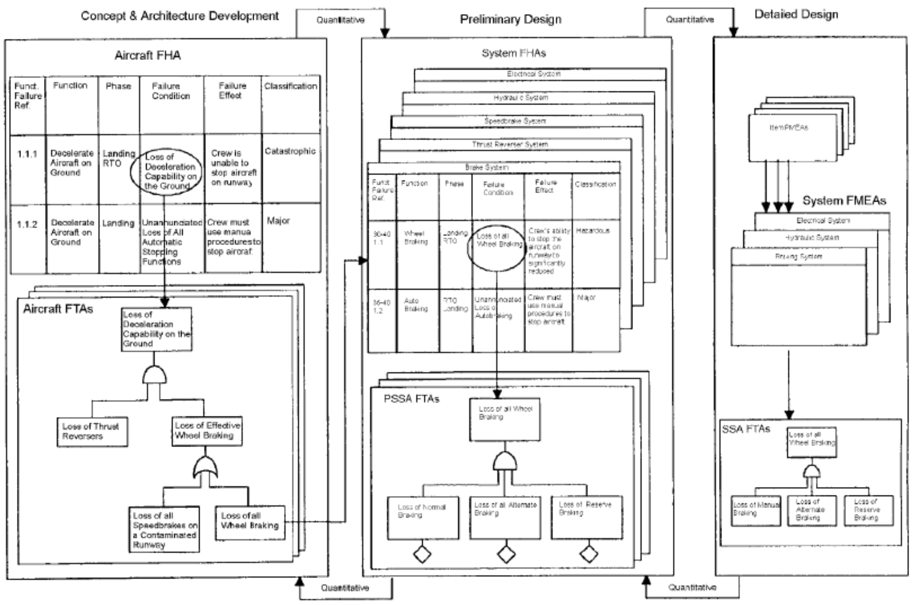
According to the guidance of SAE ARP4761, the SSAs for Flying Crane should start with the PSSA FTA.

Appendix Figure B-9 gives out the Safety Assessment Diagram, in detailed design, the FTA and FMEA need to be considered following the FHA and FTA in preliminary design.

Appendix Figure B-10 shows the overall relationship between the FHA/FTA/FMEA. The figure shows an example of how the FHAs generate the top level events in the FTAs. The figure also highlights how the quantitative results from FMEA and FTA feed back into the system level and aircraft level FTAs to show compliance with numerical safety requirements from FHAs.



Appendix Figure B-9 Safety Assessment Diagram



Appendix Figure B-10 Example of Relationship Between FHAs and FTA/FMEAs

B.4.3 FHA

Based on the result of previous groups, FHA is updated illustrated in Appendix Table B-11.

Appendix Table B-11 Updated FHA Table

10A1	Loss Altitude	G1/G2 T1/F1~F4 /L1	See Below	
10A1a	Total loss of altitude	L1	1. In very extremely improbability condition 2. The pilot would be in trouble in controlling the aircraft. 3. Other crew and occupants fast seatbelt.	I
10A1b	Total loss of altitude	T1/ F1~F4 /L1	1. Would make the aircraft in a very extreme condition. If not recover, mission should be cancelled and search for other help. 2. Flight crew has much difficult to control a/c and go on the mission. 3. None.	II
10A1c	Lost primary altitude		1. In control 2. Increase the pilot load 3. None	III

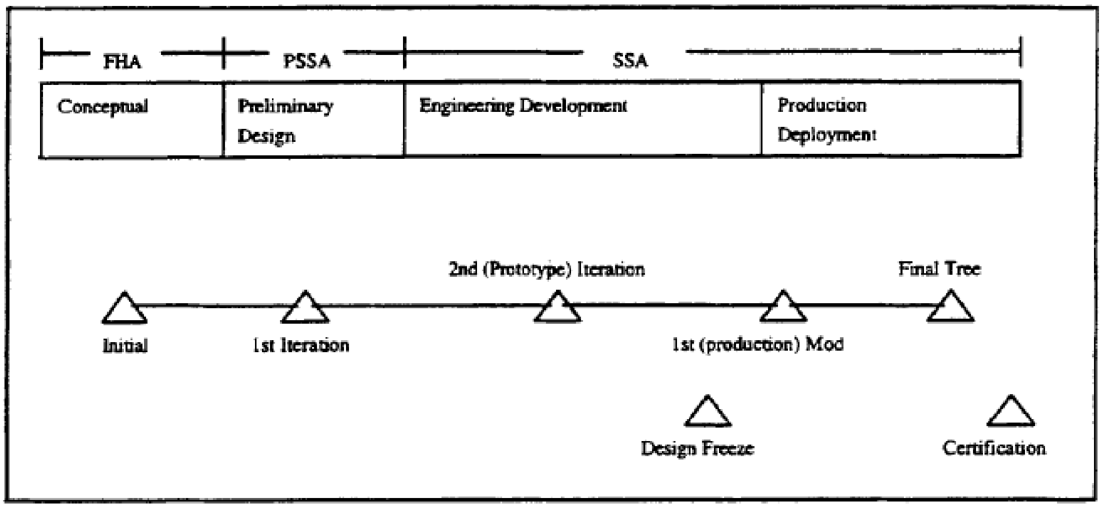
10A2	Loss Airspeed	G1/G2 T1/F1~F4 /L1	1. Would make the aircraft in a very extreme condition. If not recover, mission should be cancelled and search for other help. 2. Flight crew has much difficult to control a/c and go on the mission. 3. None.	II
10A3	Barometric altitude	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	II
10A4	Vertical speed	T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	III
10A5	Rate of Turn	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	III
10A6	Slip/Skid indicator	T1/F1~F4 /L1	1. None. 2. Increase pilot load 3. None.	IV
10A7	Heading (Stabilized)	G1/G2 T1/F1~F4 /L1	1. None. 2. Increase pilot load 3. None.	III
10A8	Navigation	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	III
10A9	Crew Alerting	G1/G2 T1/F1~F4 /L1	1. In control 2. Pilot can't know the warning 3. None	III
10A10	Weather Radar	G1/G2 T1/F1~F4 /L1	1. None. 2. Increase pilot load 3. None.	IV
10A11	Propulsion System Parameter Display	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	III

Flight Phase				Failure Condition Classification
Ground	Takeoff	In Flight	Landing	I Catastrophic II Hazardous III Major IV Minor V No Safety Effect
G1 Static G2 Taxi	T1 Takeoff	F1 Climb F2 Cruise F3 Descent F4 Approach F5 Other	L1 Landing	

B.4.4 FTA

A Fault Tree Analysis (FTA) is a deductive failure analysis which focuses on one particular undesired event and provides a method for determining causes of this event.

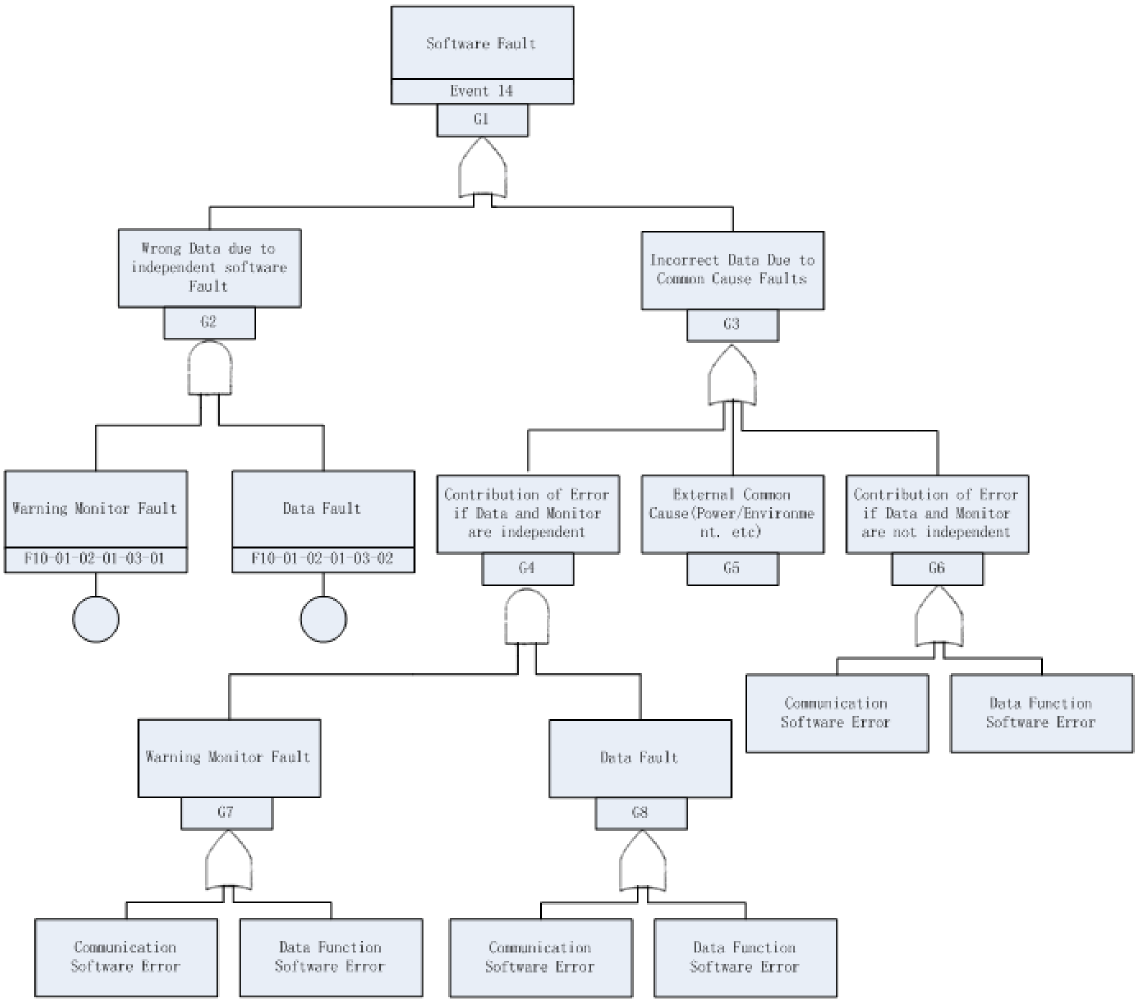
Appendix Figure B-11 shows one example of a typical FTA timeline.



Appendix Figure B-11 Example of a Typical FTA Timeline

According to all these guidance in ARP4761 and taking the FHA in preliminary design as a start, the FHA in system assessment analysis is showed in

Appendix Figure B-12 which is an example for the velocity failure：

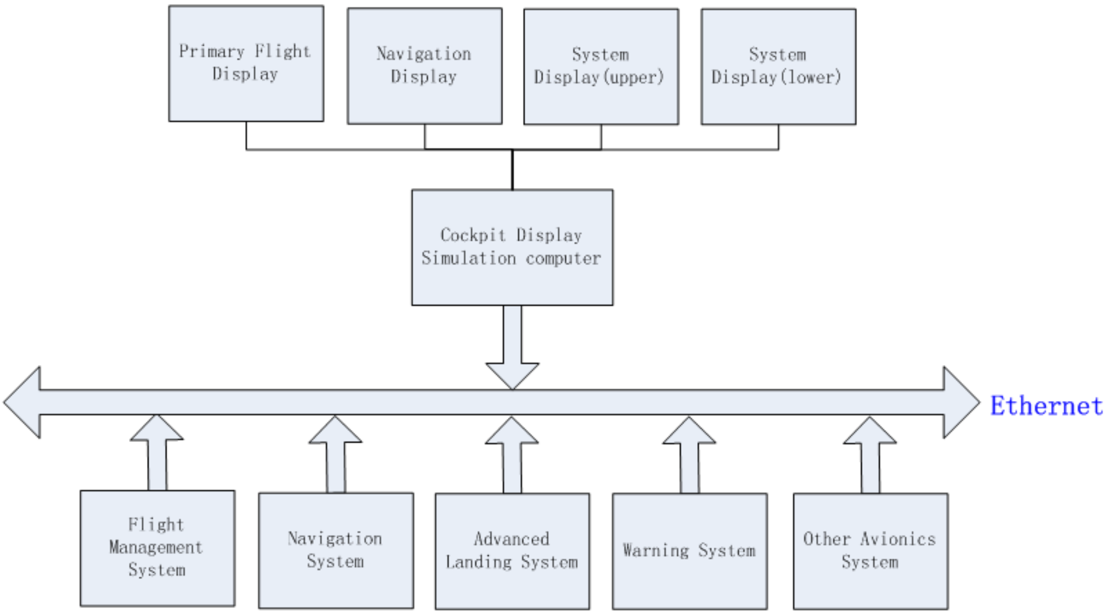


Appendix Figure B-12 Fault Tree Analysis in SSA

B.5 System Simulation

B.5.1 System Simulation Architecture

The hardware architecture of simulation for cockpit control and display system is illustrated in Appendix Figure B-13. It includes three parts: cockpit display simulation computer, Primary Flight Display LCD and Navigation Display LCD. It communicates with other subsystem such as Flight Management System, Navigation System, Advanced Landing System, Warning System and so on via Ethernet.



Appendix Figure B-13 Hardware Architecture

Display Simulation System Software run in the simulation computer, it mainly includes following modules:

1. Multi-Functional Displays Module

   This module produces the display content and format of PFD and ND.

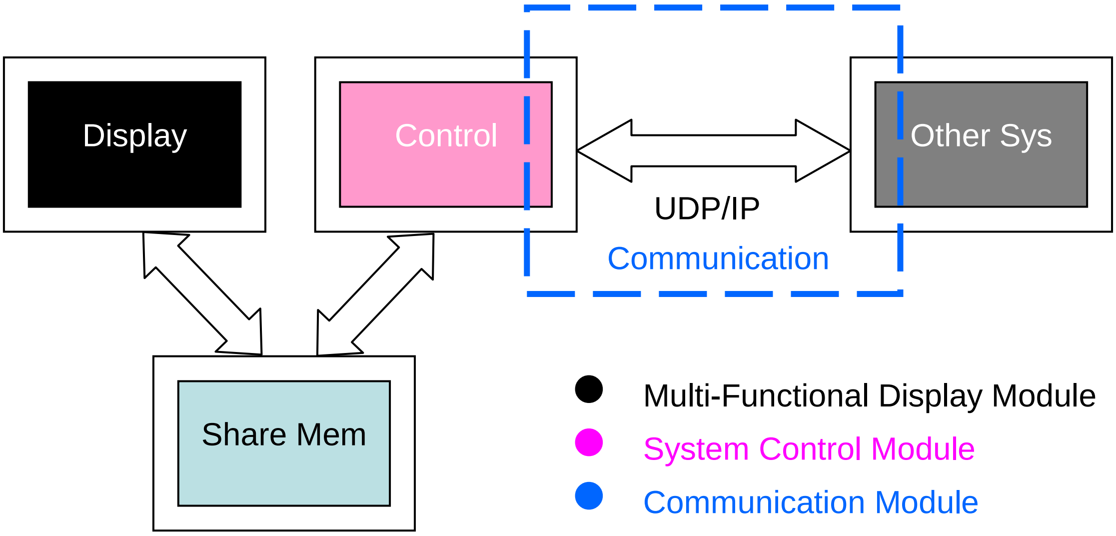
2. System Control Module

   This module is responsible for the management of whole simulation system and control the message interaction

3. Communication Module

   This module completed the task of data communication between display and drive data from other avionics subsystem.

The Software architecture is illustrated in Appendix Figure B-14.

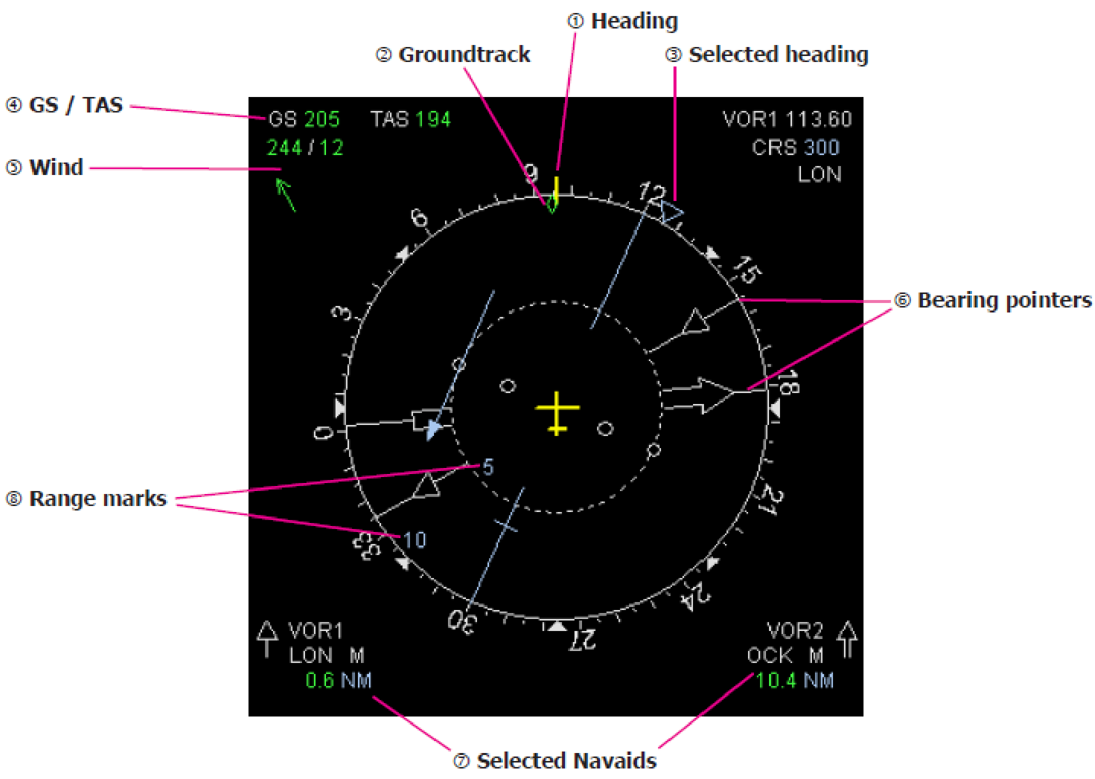


Appendix Figure B-14 Software Architecture of display simulation

B.5.2 Multi-Function Displays Module Design

Display systems simulation focus on the navigation display simulation, for some other guy has completed the primary flight display and system display.

Navigation Displays (ND) are both for Captain and First Officer located the inboard displays. They present all navigation information such as the waypoints, routine plan, navigation information and so on. The simulation for ND common information is illustrated in Appendix Figure B-15.



Appendix Figure B-15 ND common information

- Heading:

  A yellow index marks present aircraft heading on the rotating heading rose.

- Ground Track:

  Green diamond mark displays current aircraft ground track, which is different from heading in crosswind conditions.

- Selected Heading

  Blue triangle shows heading selected on FCU. It is removed when flying in managed lateral (NAV) mode. In ND ARC mode, if selected heading is outside visible arc of heading rose, it is numerically displayed at the heading arc side closet to the selected heading.

- GS/TAS

This is digital indication of current ground speed and true airspeed.

- Wind

  This is digital indication of current wind direction and speed. If wind is present, a green arrow shows wind direction relative to aircraft heading.

- Bearing Pointer

  Needles point to tuned navigation-aid stations. Appear only when a navigation-aid is selected for display on EFIS control panel.

- Selected Navigation-aids

  This is information on tuned navigation-aids selected on EFIS control panel. It includes selected receiver, navigation-aid identifier, and DME distance if available. A letter “M” is added after navigation-aid if navigation-aid is manually tuned on MCDU. A letter “R” is added if a frequency is manually tuned on Radio Management Panel (RMP, located on centre pedestal). No letters are added when navigation-aid is auto-tuned by the FMS. Arrow symbols show which bearing pointer on the rose display represents this navigation-aid.

- Range marks

  Located at range circles and define corresponding circle range from the aircraft symbol. In ND ARC mode, the outer circle represents the range selected on the EFIS control panel. In all other (ROSE and PLAN) modes, the outer circle has half the range selected on EFIS control panel.

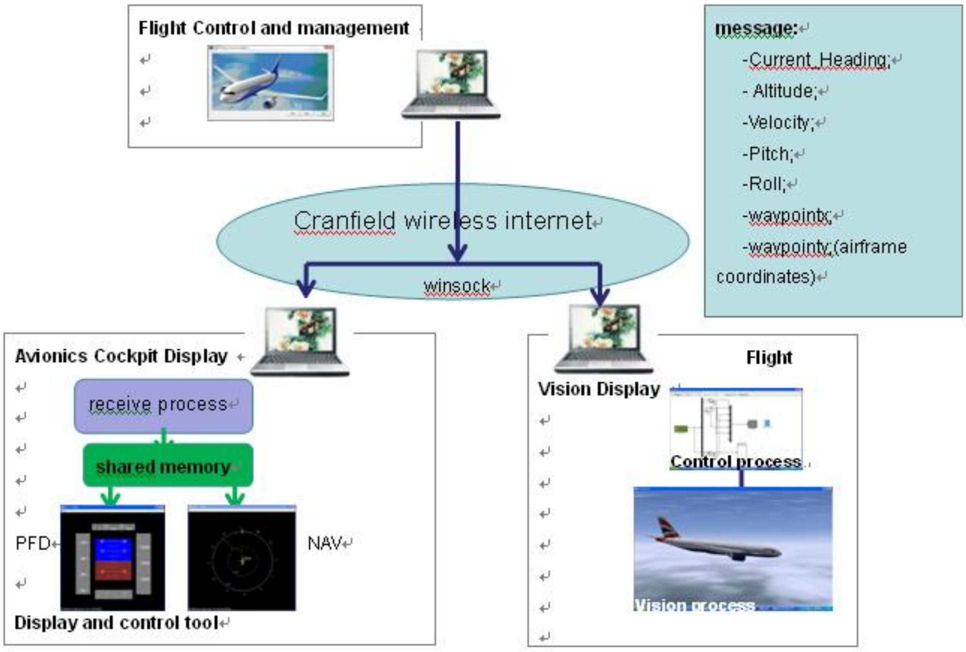
For the navigation displays, standardized colour coding in the AC25-11 (which has mentioned previously) must be advised too, such as the scale is white and the current data is green.

B.6 System Integration of simulation

The aim of avionics simulation and integration is to design a typical flight plan from BeiJing to Xi'An in China. The Simulation architecture is shown in Appendix Figure B-16.

A 3D flight route is created by management system to design and calculate relevant parameters to communication system, then output to flight control system and cockpit display system for controlling aircraft and displaying all kinds of traffic information to pilots.

The message in the network has the same structure in software of each subsystem to complete the integration of whole simulation system. The other subsystems in the simulation system are introduced as follows.

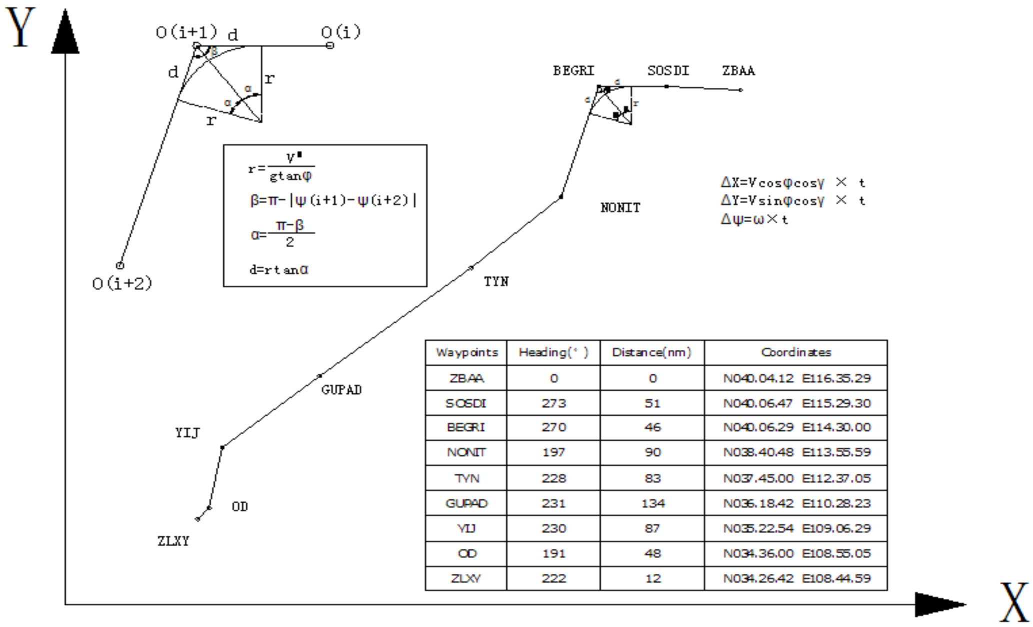


Appendix Figure B-16 Simulation Architecture

1. FMS Simulation

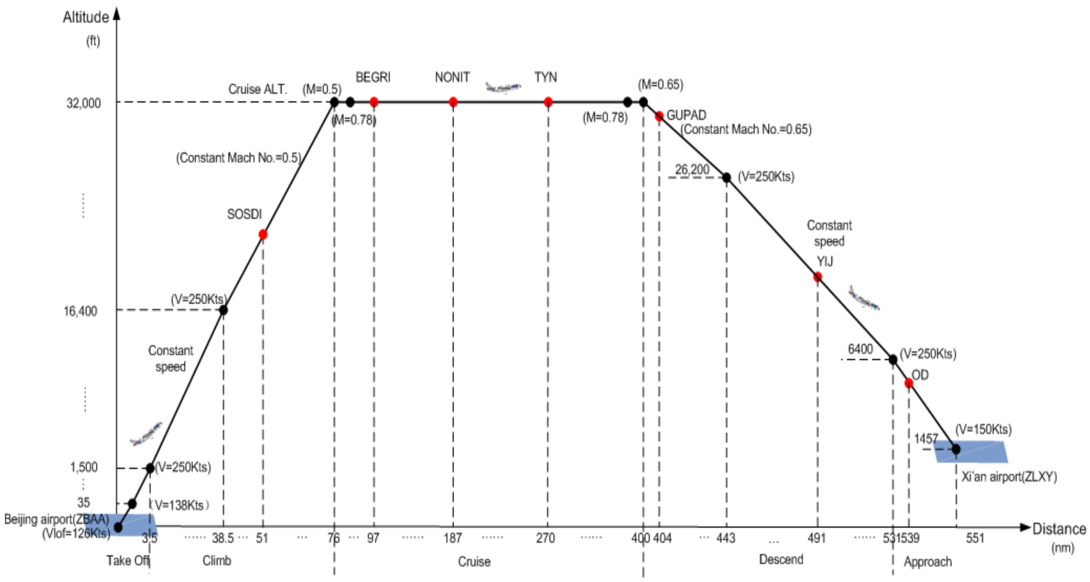
To complete the simulation of avionics system, the guy who is responsible for the Flight management system give out a typical Lateral Profile of Flight Route and Vertical Profile of Flight Route from BeiJing to Xi'An (as Appendix Figure B-17, Appendix Figure B-18 and Appendix Figure B-19 illustrated).

According to the flight route, the navigation display frame is designed by using VAPS software.

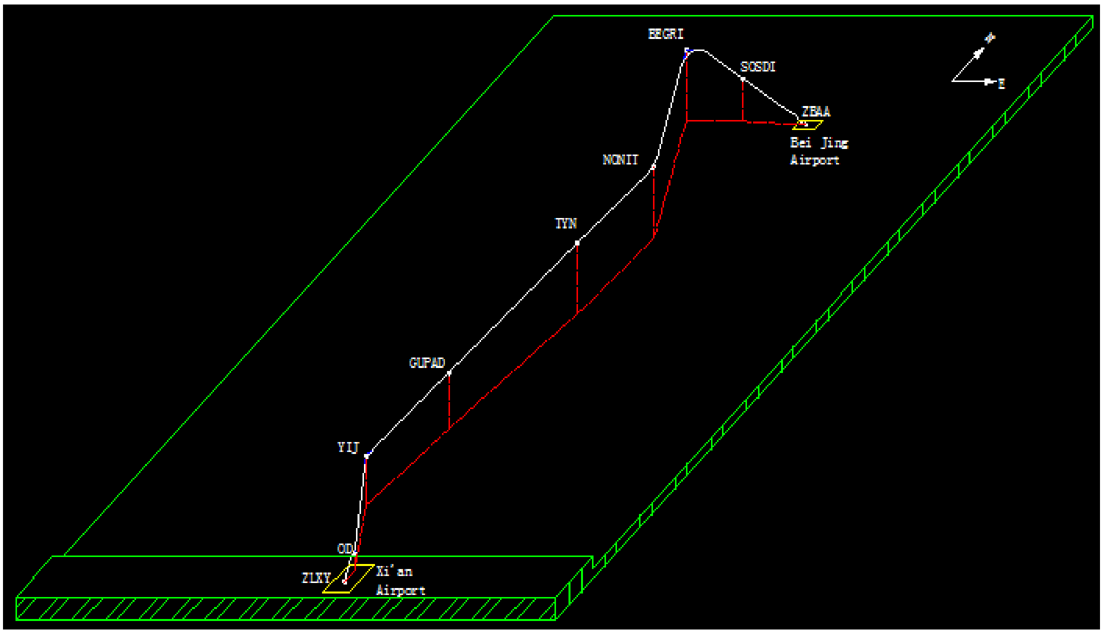


Waypoints	Heading(°)	Distance(nm)	Coordinates
ZBAA	0	0	N040.04.12 E116.35.29
SOSDI	273	51	N040.06.47 E115.29.30
BEGRI	270	46	N040.06.29 E114.30.00
NONIT	197	90	N038.40.48 E113.55.59
TYN	228	83	N037.45.00 E112.37.05
GUPAD	231	134	N036.18.42 E110.28.23
YIJ	230	87	N035.22.54 E109.06.29
OD	191	48	N034.36.00 E108.55.05
ZLXY	222	12	N034.26.42 E108.44.59

Appendix Figure B-17 Lateral Profile of Flight Route



Appendix Figure B-18 Vertical Profile of Flight Route



Appendix Figure B-19 3D of Flight Route

2. Communication System Simulation

The communication design of avionics system is responsible by another guy. The communication init, receive and close subroutine is called in main program. Via the UDP/IP communication protocol，display system can receive data in network come from other subsystem such as FCS, FMS and so on.

The communication is call in main program includes:

- Init the communication
- Receive Data
- Communication End

3. FCS Simulation

In this part, the guy who is responsible for the FCS system design uses Matlab to receive the position and attitude simulation data of aircraft from FMS data, and send it to the visual software Flight Gear. Flight Gear can get aircraft position and attitude visualization according the aircraft model which we has built in Flight Gear before. The visualization in this simulation is used to help understand the performance of aircraft.

Appendix C Enhanced Vision System

Enhanced Vision System is a related technology which incorporates information from aircraft based sensors (e.g., look forward infrared cameras, millimetre wave radar) to provide vision in limited or low visibility environments.

Enhanced Vision systems add real-time information from external sensors, such as an infrared camera and millimetre wave radar to aid the pilot’s process under low visible condition.

An important feature of the EVS is that the image from outside sensors such as IR or MMW-radar can be overlaid to the outside scene on a head-up display (HUD) so that enhanced vision system can improve the situation awareness of pilots greatly especially in some bad weather or low visibility conditions.

Enhanced Vision System is not considered in the conceptual and preliminary design of Flying Crane. Only the synthetic vision system is integrated into head-down display to enhance the situation awareness for the pilots in preliminary design. So, it starts with the requirements analysis for the enhanced vision system design.

C.1 Requirements Of Enhanced Vision System

As a new part in the avionics system, the EVS design starts with its requirement analysis. The requirements are derived from Aircraft-level Requirement and avionics system requirements.

The details of requirements for EVS will give out in Appendix Table C-1 and Appendix Table C-2.

Appendix Table C-1 Requirements for EVS

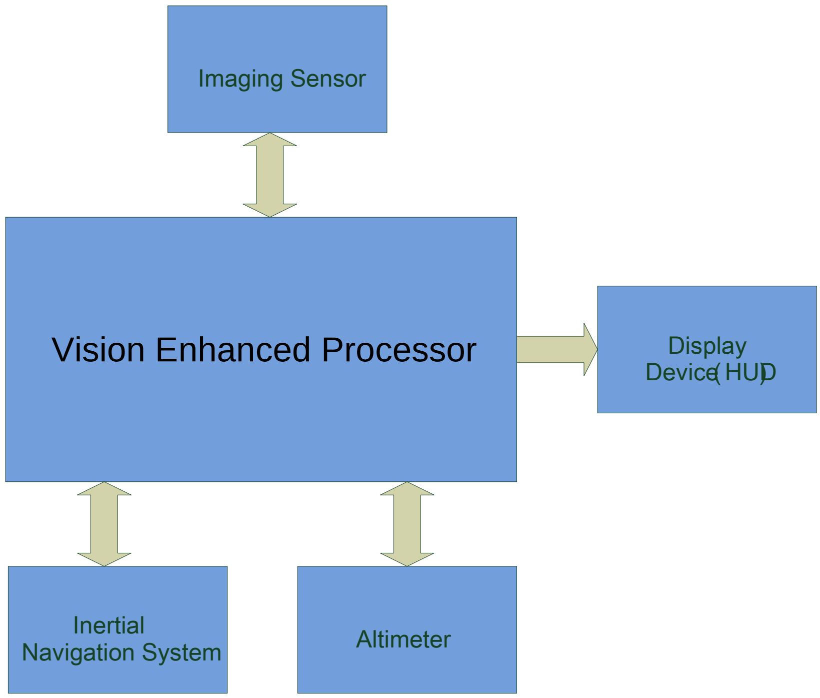
Aircraft-level Requirement	System Requirement (Ref. No)	EVS Requirement
All weather all environment	enhanced situational awareness (R-10A-103)	Terrain Information/Vision Imagery
Landing /take off safety	incorporate a taxi guidance feature (R-10A-106)	Pathway guidance display
	obstacle, runways and other land features(R-10A-110)	using real time images to integrate all of these features
Warning information	Audio-visual warning (R-10A-105)	Terrain Alerting
3-D Ground map .	'external' into a realistic view (R-10A-109)	Terrain Database Integrity
	shading/lighting/transparency / texture/mapping/hidden/surface/removal features (R-10A-115)	Terrain Depiction

Appendix Table C-2 EVS System Requirements

Range	≥ 2 nm
Field of View	≥ 30° azimuth ≥ 22.5° elevation
Image Update Rate	≥ 10 Hz
Image Latency	< 120 milliseconds
Imaging Environments	Concrete/asphalt runways, Dry/wet grass, dirt, asphalt, snow, ice on sides of runway
Image Contrast	Provide clear definition of runway edges and obstacles in airport area
Display	Conformal to real world, See through to runway, Ambient light compensation

C.2 System Architecture Design

Appendix Figure C-1 shows the enhanced vision system architecture composition.



Appendix Figure C-1 Enhanced vision system architecture diagram

The architecture of EVS includes the imaging sensor unit, the vision enhance processor and display device. It also coupled with altimeter and INS to correct and compensate the data from sensor. The optional sensors are MMWR and Forward Looking Infrared (FLIR) camera. The display device applied the Head-up display (HUD).

C.3 System Hardware Design

The EVS candidate sensors advantages/Issues are shown in Appendix Table C-3. After comparing the advantages and disadvantages of these candidate sensors, the Look Forward Infra Red camera and Millimetre Wave Radar (MMWR) are chosen as the sensors in Flying Crane.

The major characteristics of these two sensors are illustrated in Appendix Table C-4. Analyzing these parameters we can see the IR can provide a good image quality and the WWMR has a better weather penetration. Therefore，fusing images from these two sensors can give pilots good real-time situation awareness for safety operation.

Appendix Table C-3 EVS candidate sensors advantages/Issues

SENSOR	ADVANTAGES	ISSUES
X-Band Active Scanning	• Multifunction with weather and windshear • All weather • Radome compatible	• Resolution • EMI • Scene registration • Object height • Data loss
MMW Active W-Band	Resolution (0.3°) with 30-inch aperture	• Same as X-Band • Weather penetration • Aperture integration • Little low grazing angle reflectivity data • Technology Status
Active K-Band	• Resolution (0.7°) with 30-inch aperture • Weather penetration better than W-Band	Same as W-Band
MMW Passive Camera	• Better weather penetration than IR • Radiometric, one-way loss • Limited EMI	• Aperture integration • Development state • Temperature Gradient Sensitivity • Resolution?
Infrared Passive Camera	Image quality	• Poor weather and fog penetration • Aperture integration • IR window
Optical • Low-light level TV • Enhanced	Image quality	• Technology

Appendix Table C-4 Parameters of FLIR and MMWR

	Imaging	Image Rate	Resolution	Advantage
FLIR	2-D	>25	0.05°	Good Image Quality
MMWR	Angle/Range	15	0.25° /6m	Good Weather penetration

C.3.1 Look Forward Infrared Camera

For the look forward Infrared camera, EVSII of Kollsman is chosen for Flying Crane. The characteristics are illustrated by Appendix Table C-5.

Appendix Table C-5 Characteristics of EVSII

Field Of View	30 Degrees Horizontal by 22.5 Degrees Vertical (*Nominal)
Power	+28 VDC Aircraft Power, 120W avg., 300W peak
LRU's	- Forward Looking Infrared (IR) Sensor - Processor - IR Window
Video Outputs	SMPTE-170M Analog Video, SMPTE 259 digital video
Control Interfaces	RS232, RS422, ARINC 429, Discretes
System Weight	22 lbs. Maximum (FLIR: 12lbs., Processor: 8lbs., IR Window: 2lbs.)
FPA Size	320 H x 240 V pixels InSb FPA
Sensitivity (NETD)	Less than 5 mK
IR Spectrum	1 to 5 Micron
Temperature Range	-55C to +70C
Altitude Range	Up to +55,000 Feet
Design Standards	RTCA DO-178B, DO-254, And DO-160 Compliant

EVS II can provide safe flight operations to pilots in darkness, smoke, rain, fog, and other low visibility conditions. It mainly contains three units: IR sensor, processor and even the IR window.

Therefore it is easy to install in all kinds of aircraft. It includes three LRUs as Appendix Figure C-2 shows: forward looking infrared sensor, Processor and IR window.

Appendix Figure C-2 LRUs of EVSII

C.3.2 Millimetre Wave Radar

There are two choices for the Millimetre Wave Radar. The first one is W-Band 94 GHz MMW Radar of BAE. Appendix Table C-6 shows the characteristics of this radar. The second one is Romeo II Millimetre Wave Radar of Thomson-CSF which technical data are illustrated by Appendix Table C-7. Romeo II is a small, lightweight millimetre wave radar suitable for fitting to all types of helicopters and fixed-wing aircraft which has been designed to enable safe operations at low level by day and night under all weather conditions. It offers avoidance of obstacles down to the size of electrical wires, and landing assistance. Take the performance and installation into consideration, the Romeo II is applied by Flying Crane.

Appendix Table C-6 Characteristics of W-Band 94 GHz MMW Radar

System Weight	45.35kg
Scanned Area	+/-15 deg
Antenna Measure	609*254*229
Band	94 GHZ
Advantage	See through high droplet:
	rain, fog and dust

Appendix Table C-7 Technical Data Of Romeo II

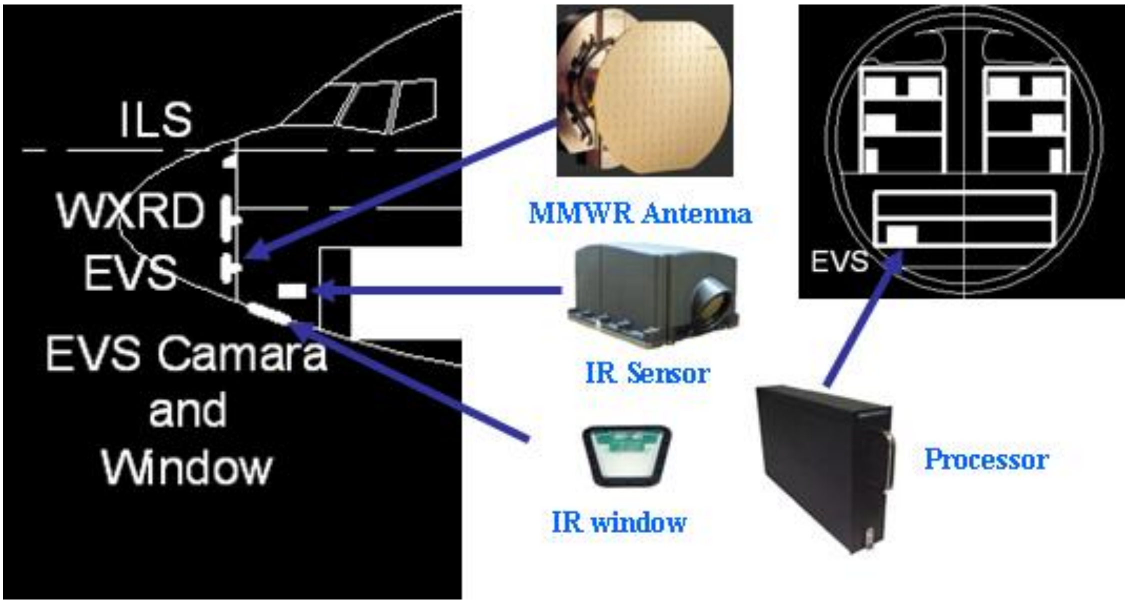
System Weight	Processing Unit	12kg
	Antenna	11kg
	Control Unit	1kg
Dimensions	Processing Unit	315×190×190
	Antenna	240×240×320
	Control Unit	145×110×70
Frequency		94 GHZ
Power output		400mW
Range		up to 3,000m

C.3.3 Installation Of Hardware

Following the hardware decision, the installation in the aircraft is considered. The EVS sensor is typically installed in the front of windscreen above the nose or below the nose. Appendix Figure C-3 gives out the two typical ways of installation for EVSII.

Appendix Figure C-3 Typical ways of installation for EVSII

The installation in Flying Crane of EVS devices is showed in Appendix Figure C-4. The sensors are installed under the nose can present a good view for the sensors, especially during the landing phase.



Appendix Figure C-4 Installation of EVS devices

C.4 FHA for EVS

Following the process introduced previously, the FHA for EVS is given out by Appendix Table C-8.

Appendix Table C-8 FHA for EVS

Failure Condition Ref.	Failure Condition (Hazard Description)	Flight Phase	Effect on Aircraft/Occupants 1. Aircraft 2. Crew 3. Cabin occupants	Classification
EVS-A1	incorrect of image		See Below	
EVS-A1a	Incorrect image of DEM	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	IV
EVS-A1b	Incorrect image of real sensor	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	IV
EVS-A1c	Image process/fusion error	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	IV
EVS-A2	Incorrect flight guidance information	G1/G2 T1/F1~F4 /L1	1. In control 2. No guidance for pilots 3. None.	IV
EVS-A3	Incorrect navigation data		See Below	
EVS-A3a	Incorrect position and altitude data	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	III
EVS-A3b	Incorrect data merging	G1/G2 T1/F1~F4 /L1	1. In control 2. Increase the pilot load 3. None	III
10A4	Incorrect warning message	G1/G2 T1/F1~F4 /L1	1. In control 2. No effect 3. None	IV

Flight Phase				Failure Condition Classification
Ground	Takeoff	In Flight	Landing	I Catastrophic II Hazardous III Major IV Minor V No Safety Effect
G1 Static G2 Taxi	T1 Takeoff	F1 Climb F2 Cruise F3 Descent F4 Approach F5 Other	L1 Landing	