Universidad Rey Juan Carlos

DEGREE IN AEROSPACE ENGINEERING IN AIR NAVIGATION

Collection of Laboratories
Course on Aerospace Engineering

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Contents

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Introduction to MATLAB

1.1   What is MATLAB?

MATLAB$^\circledR$ is a high–performance language for technical computing. It integrates computation, visualization, and programming in an easy–to–use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include:

- Math and computation.

- Algorithm development.

- Modeling, simulation, and prototyping.

- Data analysis, exploration, and visualization.

- Scientific and engineering graphics.

- Application development, including graphical user interface building.

MATLAB is a unique programming language and development environment that features many advantages over other programming languages. As mentioned, it is very easy to use, constantly enhances its plotting capabilities, utilizes that latest trends in computer architecture, allows working together with other languages (C/C++, Java), and enables real–time implementation for data acquisition, image processing, and control of autonomous vehicles and robots, i.e., applications that many engineering students need and will need in their professional career. These factors have made MATLAB/Simulink quite popular in engineering universities worldwide.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computation problems, especially those with matrix and vector formulations, in much less time it would take to write a program in a scalar non–interactive language such as C or Fortran.

MATLAB features a family of application–specific solutions called toolboxes. Toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M–files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, optimization, aerospace, and many others.

1.2   The MATLAB system

The MATLAB system consists of five main parts:

Development Environment: This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It introduces the MATLAB desktop and Command Window, a command history, and browsers for viewing help, the workspace, files, and the search path.

The MATLAB Mathematical Function Library: This a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and Fourier transforms.

The MATLAB Language: This a high level matrix/array language with control flow statements, functions, data structures, input/output, and object–oriented programming features.

Handle Graphics®:   This is the MATLAB graphics system. It includes high–level commands for 2-dimensional and 3-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low–level commands that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

The MATLAB Application Program Interface (API):   This a library that allows you to write C and Fortran programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT–files.

1.3   The MATLAB documentation

MATLAB provides extensive documentation, in both printed and online format. The online Help provides task–oriented and reference information about MATLAB features. The MATLAB documentation is also available in printed form and in PDF format.

2

Laboratory 1: Aerodynamics

Using the given software **PABLO** and the airfoil database **Airfoil bank**, the students should complete a memory consisting of:

1 Choose 4 airfoils among the 4-digit series. Plot them, and identify its main characteristics.[1]

Consider incompressible flow. Consider an aircraft flying at $h = 11000$ m in a determined incompressible velocity regime. The characteristic chord can be considered as $c = 5$ m. The viscosity of air can be considered as $\mu = 0,000018 \; Ns/m^2$

2 Plot the main characteristic curves of the 4 airfoils. Compare them and discuss the effects of thickness, camber and angle of attack in the generation of lift.

3 You will observe that the coefficient of lift curves does not include stall effects. According to the information given in regard of laminar flow, turbulent flow, laminar to turbulent transition, and boundary ayer drop off (separation):

   3.1 Discuss the phenomena which make the aircraft stall.

   3.2 Modify the coefficient of lift curve of one of the airfoils to include the stall.

4 Design your own airfoil.

   4.1 State the design requirements and justify your selection.

   4.2 Give the camber and thickness as a function of x.

   4.3 Plot your designed airfoil for an angle of attack $\alpha = 5$.

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[1]Notice that the 4 airfoils should be chosen combining different cambers and thickness. In particular, choose at least one symmetric airfoil

    4.4 Make up[2] a distribution of pressures made of 8 points in extrados and 8 points in intrados. Plot two curves fitting, respectively, the sets of points.

    4.5 Obtain the coefficient of lift by integrating the distributions.

The students are allowed to team up in work groups formed by 3 people each. A laboratory memory should be completed and submitted in time and form.

Goals and competences:

- Understanding the potentiality of Matlab for solving engineering problems.

- Acquire abilities to work in teams, discuss and reach to conclusions.

- Acquire abilities to write a laboratory memory.

- Understanding the aerodynamics of airfoils.

Constraints:

- There is NO limitation on the number of pages.

Recommendations:

- Use any of the available text editors, for instance Microsoft Word. However, it is **strongly recommended to use Latex**.

- Structure the memory as usual: section, subsections; include an index of contents, an index of figures and tables, and a bibliography.

- Try to very briefly introduce and motivate the topic.

- Try to very briefly wrap up and make some conclusions.

- Dedicate a brief section to material, software, hardware, etc.

- Use figures and tables to expose experimental data and results.

- Try to discuss all achieved results, both when you obtained the expected and when you did not. If not, discuss why?

- The implemented code must go into an appendix.

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[2]In principle, the distribution of pressures is calculated such we have seen in 2. with Pablo. However, this course does not cover such calculations. Therefore, we just "make up" a distribution that necessary will look similar to the canonical one

Evaluation

The evaluator will consider:

- Quality of the content of the laboratory memory (around 60%).

- Originality of the work (around 40%).

Administrative issues:

- Assignment date: February the 14th, 2013; Thursday.

- Report submission (only pdf allowed): February the 21th, 2013; Thursday.

3

Laboratory 2: Mechanics of flight

This laboratory consist in obtaining and analyzing the 3DOF performances of a BADA model aircraft.

BADA is a collection of ASCII files, which specifies operation performance parameters and operating procedure parameters for 295 aircraft types. These parameters of aircraft performance and the model is designed for use in trajectory simulation and prediction algorithms within the domain of Air Traffic Management (ATM). All files are maintained within a configuration management system at the Eurocontrol Experimental Centre (EEC) at BrŐtigny-sur-Orge, France. A complete description of BADA is available in the BADA 3.6 User Manual [**?**]. User Manual for Revision 3.6 of BADA provides definitions of each of the coefficients and then explains the file formats. Instructions for remotely accessing the files via Internet are also given.

The students should complete a memory consisting of the evolution of the state variables over time $(V(t), \gamma(t), \chi(t), x_e(t), y_e(t), h_e(t), m(t))$, including the 4D trajectory (x_e, y_e, h_e, t), in a typical flight of a commercial transportation aircraft.

Each group will choose an aircraft type among those in BADA database (See [?]), writting down all needed parameter of the selected aircraft. (See *A320.txt* as example of needed data for an Airbus 320)[1].

In order to obtain the 4D trajectory, the flight will be divided into three phases: climb, cruise, and descent.

1 The climb phase will be assumed to be a symmetric flight into the vertical plane non considering any wind and assuming the heading angle to be zero. Therefore, the ODE system to be used is as follows:

$$m\dot{V} = T - D - mg\sin\gamma,$$
$$mV\dot{\gamma} = L - mg\cos\gamma,$$
$$\dot{x}_e = V\cos\gamma,$$
$$\dot{h}_e = V\sin\gamma,$$
$$\dot{m} = -T\eta.$$

where $\eta = (\frac{C_{f1}}{(1000*60)}) * (1 + \frac{V}{C_{f2}})$, with V in knots.

In order to solve the system, you should:

1.1 Set the initial conditions for all the state variables, initial and final time. This conditions must be selected according to typical values of aircraft performance.

1.2 Use the function *Ode23* to integrate the system. See *Paper plane* as example of its use.

1.3 Set the control variables $(T(t), C_L(t))$[2] to the following values:
   * $T = 0.8 * T_{max}$, where $T_{max} = C_{tc1} * (1 - \frac{h_e}{C_{tc2}} + C_{tc3} * (h_e)^2)$, and h_e goes in feet.
   * $C_L = C_{L_{opt}}$

1.4 Plot the obtained results for this portion of the flight.

1.5 Discuss the obtained results.

2 The cruise phase will be assumed to be a symmetric flight into the horizontal plane not considering any wind. Therefore, the ODE system to be used is as follows:

$$m\dot{V} = T - D,$$
$$mV\dot{\chi} = L\sin\mu,$$
$$\dot{x}_e = V\cos\chi,$$
$$\dot{y}_e = V\sin\chi,$$
$$\dot{m} = -T\eta,$$

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[1]Notice that A320 can not be selected, you are constrained to choose any other aircraft instead.

[2]Notice that in principle the control variables are set either by the pilot or by the FMS. In our case, we will set the values in advance. Notice that C_L acts as control

being $L = \frac{mg}{\cos \mu}$. In order to solve the system, you should:

2.1 Set the initial conditions for all the state variables, initial and final time. Initial conditions and initial time will coincide with the final conditions of the previous phase. Set the final time according to typical values of aircraft performance.

2.2 Use the function *Ode23* to integrate the system. See *Paper plane* as example of its use.

2.3 Set the control variables $(T(t), \mu(t))$ to the following values:

* $T = 0.5 * T_{max}$,
* Set μ using tabular data. Use matlab function *interp1* to interpolate data within time.

2.4 Plot the obtained results for this portion of the flight.

2.5 Discuss the obtained results.

3 The landing phase will be assumed to be gliding performance not considering any wind. Therefore, the ODE system to be used is as follows:

$$m\dot{V} = -D - mg \sin \gamma,$$
$$mV\dot{\gamma} = L - mg \cos \gamma,$$
$$\dot{x}_e = V \cos \gamma,$$
$$\dot{h}_e = V \sin \gamma,$$

3.1 Set the initial conditions for all the state variables, initial and final time. Initial conditions and initial time will coincide with the final conditions of the previous phase. Set the final time according to typical values of aircraft performance.

3.2 Use the function *Ode23* to integrate the system. See *Paper plane* as example of its use.

3.3 Set the control variable $(C_L(t))$ to the following value:

* $C_L = C_{L_{opt}}$.

3.4 Plot the obtained results for this portion of the flight.

3.5 Discuss the obtained results.

4 Plot the complete evolution of the variables with time merging the three phases. Plot also the complete 4D trajectory. Discuss the obtained results

The students are allowed to team up in work groups formed by 3 people each. A laboratory memory should be completed and submitted in time and form.

Goals and competences:

- Understanding the potentiality of Matlab for solving engineering problems.

- Acquire abilities to work in teams, discuss and reach to conclusions.

- Acquire abilities to write a laboratory memory.

- Understanding the fundamentals of mechanics of flight.

Constraints:

- There is NO limitation on the number of pages.

Recommendations:

- Use any of the available text editors, for instance Microsoft Word. However, it is **strongly recommended to use Latex**.

- Structure the memory as usual: section, subsections; include an index of contents, an index of figures and tables, and a bibliography.

- Try to very briefly introduce and motivate the topic.

- Try to very briefly wrap up and make some conclusions.

- Dedicate a brief section to material, software, hardware, etc.

- Use figures and tables to expose experimental data and results.

- Try to discuss all achieved results, both when you obtained the expected and when you did not. If not, discuss why?

- **The implemented code must go into an appendix.**

Evaluation:

The evaluator will consider:

- Assessment of points 1,2,3,4 and quality of the content. (around 80%).

- Quality of the of the laboratory memory (around 20%).

Administrative issues:

- Assignment date: April the 4th, 2013; Thursday.

- Report submission (only pdf allowed): April the 12th, 2013; Friday.

4

Laboratory 4 & Assignment 5:

Air Navigation

This statement contains both Laboratory 4 and Assignment 5. It consists in completing and describing a flight plan prior departure, taking into account the characteristics of the air navigation system, in particular, the CNS-ATM concept. Using matlab, calculate the 4D trajectory to fulfill such flight plan. BADA database will be used as aircraft performance model.

Each group will choose an aircraft type among those in BADA database and complete a memory consisting of:

1 Setting and describing your own flight plan: In order to do it, you should:

    1.1 Choose origin and destination airport.

    1.2 Consult the proper Navigation charts in the corresponding AIP (see link in moodle for AENAs AIP), and select:

        ∗ A runway head for departure.

        ∗ A SID procedure for take off and initial climb.

        ∗ The desired Flight Level.

        ∗ A couple of waypoints that describe the En-Route part of the flight.

        ∗ A STAR procedure for approach.

        ∗ A final approach procedure with a Runway head for landing.

    1.3 Discuss your selection.

2 Regarding the Air Navigation System:

    2.1 How the different levels of Air Traffic Management affect you flight plan? (In terms of airspace structure, airspace capacity and airspace control).

    2.2 Throughout which volumes of responsibility does the aircraft fly during the flight? (in terms of FIR/UIR; ATC sectors; Volumes of control).

2.3 What kind of services are being provided inside such volumes? (In terms of CNS services in the different phases of the flight).

Simulate now the flight using matlab. In order to do that:

3 Assume a 3D motion over an spherical earth. Therefore, the ODE system to be used is as follows:

$$m\dot{V} = T - D - mg\sin\gamma,$$
$$mV\dot{\chi}\cos\gamma = L\sin\mu,$$
$$mV\dot{\gamma} = L - mg\cos\gamma,$$
$$\dot{\lambda} = \frac{V\cos\gamma\cos\chi}{R_e\cos\theta},$$
$$\dot{\theta} = \frac{V\cos\gamma\sin\chi}{R_e},$$
$$\dot{h}_e = V\sin\gamma,$$
$$\dot{m} = -T\eta.$$

where λ and θ are, respectively, longitude and latitude (both in radians), and R_e is the radius of earth. $\eta = (\frac{C_{f1}}{(1000*60)}) * (1 + \frac{V}{C_{f2}})$, with V in knots.

In order to simulate the whole flight, it is recommended to divide the flight into phases, each governed by a simplified ODE subsystem (vertical, horizontal).

In order to solve the system, you should:

3.1 Set the initial conditions for all the state variables, initial and final time. This conditions must be selected according to typical values of aircraft performance and also taking into account the orientation of the taking-off runway. Since aircrafts take off with flaps deflected, take the TO configuration in BADA.

3.2 Use the function *Ode23* to integrate the system. Notice that in this case, each of the sub-phases will finish based on a trigger condition, for instance: a velocity (to switch flap configuration); a waypoint; a radial. In order to introduce this fact in the function *Ode23*, see matlab help:

> *Ode23*
> *odeset*
> *Event Location Properties*

3.3 Notice that the control variables $(T(t), \mu(t), C_L(t))$[1] should be set to adequate values.

3.4 Plot the relevant results for each of the phases in which you divide your flight simulation.

3.5 Discuss the obtained results for each of the phases in which you divide your flight simulation.

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[1]Notice that in principle the control variables are set either by the pilot or by the FMS. In our case, we will set the values in advance. Notice that C_L acts as control

4 Plot and discuss.

    4.1 Plot the complete evolution of the variables with time merging all phases.

    4.2 Plot also the complete trajectory (latitude, longitude, altitude) in a 3D plot.

    4.3 Using the given script *map.m* plot the 2D (latitude, longitude) trajectory over the map of your area of interest (Spain, Europe, EEUU, etc.)[2]

    4.4 Discuss the obtained results.

The students are allowed to team up in work groups formed by 4 people each. A laboratory memory should be completed and submitted in time and form.

Goals and competences:

- Understanding the potentiality of Matlab for solving engineering problems.

- Acquire abilities to work in teams, discuss and reach to conclusions.

- Acquire abilities to write a laboratory memory.

- Understanding the fundamentals of air navigation.

- Understanding the fundamentals of the CNS–ATM concept.

- Acquire abilities to read and understand navigation charts.

Constraints:

- There is NO limitation on the number of pages.

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[2]Notice that the map is plotted using a Miller projection, so the computed latitude and longitude must be transformed according to Miller projection.

Recommendations:

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Evaluation:

The evaluator will consider:

- Assessment of points 1,2,3,4 and quality of the content. (around 80%).

- Quality of the of the laboratory memory (around 20%).

Administrative issues:

- Assignment date: April the 18th, 2013; Thusday.

- Report submission (only pdf allowed): April the 30th, 2013; Tuesday.