Calculating Aerodynamic & Stability Characteristics For Small fixed-wing UAVs based on Digital DATCOM

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Abstract*– UAV importance has increased especially nowadays and of course building an accurate model for the design is essential for accurate results and good control for UAVs. The model we build here is an aerodynamic model to calculate aerodynamic coefficients that are used to calculate forces acting on the vehicle to control the vehicle. Creating a model for calculating aerodynamic coefficients can be made by many methods. The method we used for building a model in this paper is DATCOM can be immensely confusing. There are no point-and-click interfaces here, only points in space. This tutorial aims at helping the novice user build a simple DATCOM model and test it. The numbers obtained may not be correct, but the model should be fairly accurate (except for a few assumptions). Digital Datcom calculates static stability, high-lift, control device, and dynamic-derivative characteristics. The computer program also offers a trim option that computes control deflections and aerodynamic data for vehicle trim at subsonic Mach numbers.

***Keywords*—small fixed-wing UAV, modeling, aerodynamic data, Datcom, aerodynamic model.**

I. Introduction

In design operations, using fast estimation of aerodynamic, stability, and control characteristics is necessary to achieve because complex estimation methods need expensive systems and cost time. Before explaining the method we used, we first can give a simple definition of modeling that it is expressing any physical thing or vehicle by transfer functions that are used in the mathematical model to simplify the calculations. We here use Digital Datcom to calculate the aerodynamic coefficient we need to build a satisfying model to use in our design of the project UAV. We have in UAVs five models we have as a case study to use the resulted equations in a dynamic model to calculate UAV 12-states (positions in X, Y , Z, attitude angles (rolling, pitching, and yawing angles) velocities in X , Y, Z and angular rates p,q,r). We will briefly explain the aerodynamic modeling importance and then express the Datcom method in detail: the way we use, the software used, the name list and its definitions and finally the code we use and results.

II. AERODYNAMIC MODEL

The aerodynamic model is one of five models that are used express the UAV in equations used in dynamic model. The five models are atmospheric model, propulsion model, actuation model, geometric model and finally the model we have in this paper. The aerodynamic model is used to calculate aerodynamic stability coefficients and characteristics used in dynamic model in force and moment equations. There are six aerodynamic coefficients describing the aerodynamics of an aircraft, all depending on various inputs: relative wind speed V∞, angle of attack α, sideslip angle β, angular rates and control deflection

angles δ. The aerodynamic coefficients $C_{m_\alpha}, C_{l_\beta}, C_{n_\beta}, C_{m_q}, C_{l_p}$ and C_{n_r} are referred to as stability derivatives because their values determine the static and dynamic stability of the MAV. Static stability deals with the direction of aerodynamic moments as the MAV is perturbed away from its nominal flight condition. If the moments tend to restore the MAV to its nominal flight condition, the MAV is said to be statically stable. Most aircraft are designed to be statically stable. The coefficients $C_{m_\alpha}, C_{l_\beta}$ *and* C_{n_β} determine the static stability of the MAV. They represent the change in the moment coefficients with respect to changes in the direction of the relative airspeed, as represented by α and β. C_{m_α} is referred to as the longitudinal static stability derivative. For the MAV to be statically stable, C_{m_α} must be less than zero. In this case, an increase in α due to an updraft would cause the MAV to nose down in order to maintain the nominal angle of attack. C_{l_β} is called the roll static stability derivative and is typically associated with dihedral in the wings. For static stability in roll, Clβ must be negative. A negative value for Clβ will result in rolling moments that roll the MAV away from the direction of sideslip, thereby driving the sideslip angle β to zero. Cnβ is referred to as the yaw static stability derivative and is sometimes called the weathercock stability derivative. If an aircraft is statically stable in yaw, it will naturally point into the wind like a weathervane (or weathercock). The value of Cnβ is heavily influenced by the design of the tail of the aircraft. The larger the tail and the further the tail is aft of the center of mass of the aircraft, the larger Cnβ will be. For the MAV to be stable in yaw, Cnβ must be positive. This simply implies that for a positive sideslip angle, a positive yawing moment will be induced. This yawing moment will yaw the MAV into the direction of the relative airspeed, driving the sideslip angle to zero. Dynamic stability deals with the dynamic behaviour of the airframe in response to disturbances. If a disturbance is applied to the MAV, the MAV

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is said to be dynamically stable if the response of the MAV damps out over time. If we use a second-order mass-spring-damper analogy to analyze the MAV, the stability derivatives $C_{m_\alpha}, C_{l_\beta}$ *and* C_{n_β} behave like torsional springs, while the derivatives C_{m_q}, C_{l_p} and C_{n_r} behave like torsional dampers. The moments of inertia of the MAV body provide the mass. As we will see in chapter 5, when we linearize the dynamic equations of motion for the MAV, the signs of the stability derivatives must be consistent in order to ensure that the characteristic roots of the MAV dynamics lie in the left half of the complex plane. Cmq is referred to as the pitch damping derivative, Clp is called the roll damping derivative, and Cnr is referred to as the yaw damping derivative. Each of these damping derivatives is usually negative, meaning that a moment is produced that opposes the direction of motion, thus damping the motion. The aerodynamic coefficients Cm-δe, Cl-δa, and Cn-δr are associated with the deflection of control surfaces and are referred to as the primary control derivatives. They are primary because the moments produced are the intended result of the specific control surface deflection. For example, the intended result of an elevator deflection δe is a pitching moment m. Cl-δr and Cn-δa are called cross-control derivatives. They define the off-axis moments that occur when the control surfaces are deflected. Control derivatives can be thought of as gains. The larger the value of the control derivative, the larger the magnitude of the moment produced for a given deflection of the control surface.

III. DATCOM METHOD

The Digital Datcom basic input data unit is the "case." A "case" is a set of input data that defines a configuration and its flight conditions. The case consists of inputs from up to four data groups. • Group I inputs define the flight conditions and reference dimensions. • Group II inputs specify the basic configuration geometry for conventional configurations, defining the body, wing and tail surfaces and their relative locations. • Group III inputs specify additional configuration definition, such as engines, flaps, control tabs, ground effects or twin vertical panels. This input group also defines those "special" configurations that cannot be described using Group II inputs and include low aspect ratio wing and wing-body configurations, transverse jet control and hypersonic flaps. • Group IV inputs control the execution of the case, or job for multiple cases, and allow the user to choose some of the special options, or to obtain extra output. INPUT TECHNIQUE Two techniques are generally available for introducing input data into a Fortran computer program: namelist and fixed format. Digital Datcom employs the namelist input technique for input Groups I, II and III since it is the most convenient and flexible for this application. Its use reduces the possibility of input errors and increases the utility of the program as follows: • Variables within a namelist may be input in any order; • Namelist variables are not restricted to particular card columns; • Only required input variables need be included; and • A variable may be included more than once within a namelist, but the last value to appear will be used. Namelist rules used in the program and applicable to CDC and IBM systems are presented in Appendix A. The user should adhere to them when preparing inputs for Digital Datcom. To aid the user in complying with the general namelist rules, examples of both correct and incorrect namelist coding are included in Appendix A. All namelist input variables (and program data blocks) are initialized "UNUSED" (1.0E-60 on CDC systems) prior to case execution. Therefore, omission of pertinent input variables may result in the "UNUSED" value to be used in calculations. However, the "UNUSED" value is often used as a switch for program control, so the user should not indiscriminately use dummy inputs. All Digital Datcom numeric constants require a decimal point. The Fortran variable names that are implied INTEGERS (name begins with I, J, K, L, M, or N) are declared REAL and must be specified in either "E" or "F" format (X.XXXEYY or X.XXX). Group IV inputs are the "case control cards." Though they are input in a fixed format, their use has the characteristic of a namelist. since (with the exception of the case termination card) they can be placed in any order or location in the input data. Use of these tables will save time in preparing namelist inputs for a specific problem. The user has the option to specify the system of units to be used, English or Metric. For clarity, the namelist variable description charts which follow have a column titled "Units" using the following nomenclature: l denotes units of length: feet, inches, meters, or centimeters A denotes units of area: ft2, in2, m2, or cm2 Deg denotes angular measure in degrees, or temperature in degrees Rankine or degrees Kelvin F denotes units of force; pounds or Newtons t denotes units of time; seconds. Specific input parameters, geometric illustrations, and supporting data are provided throughout the report. To aid the user in reading these figures, the character '0' defines the number zero and the character 'O' the fifteenth letter in the alphabet. Namelist FLTCON, defines the case flight conditions. The user may opt to provide Mach number and Reynolds number per unit length for each case to be computed. In this case, input preparation requires that the user compute Reynolds number for each Mach number, and altitude combination he desires to run. However, the program has a standard atmosphere model, which accurately simulates the 1962 Standard Atmosphere for geometric altitudes from -16,404 feet to 2,296,588 feet, that can be used to eliminate the Reynolds number input requirement and provides the user the option to employ Mach number or velocity as the flight speed reference. The user may specify Mach numbers (or velocities) and altitudes for each case and program computations will employ the atmosphere model to determine pressure, temperature, Reynolds number and other required parameters to support method applications. Also incorporated is the provision for optional inputs of pressure and temperature by the user. The program will override the standard atmosphere and compute flow condition parameters consistent with the pressure and temperature inputs. This option will permit Digital Datcom applications such as wind tunnel model analyses at test section conditions. The five input combinations which will satisfy the Mach number and Reynolds number requirements are summarized in Figure 3. If the NACA control card is used. the Reynolds number and Mach number must be defined using the variables RNNUB and MACH. Other optional inputs include vehicle weight and flight path angle (“WT” and “GAMMA”). These parameters are of particular interest when using the Trim Option. The trim flight conditions are output as an additional line of output with the trim data and the steady flight lift coefficient is output with the untrimmed data. Use of the variable LOOP enables the user to run cases at fixed altitude with varying Mach number (or velocity), at fixed Mach number (or velocity) at varying altitudes, or varying speed and altitude together. Nondimensional aerodynamic coefficients generated by Digital Datcom may be based on user-specified reference area and lengths. These reference parameters are input via namelist OPTINS, Figure 4. If the reference area is not specified, it is set equal to the theoretical planform area of the wing. This wing area includes the fuselage area subtended by the extension of the wing leading and trailing edges to the body center line. The longitudinal reference length, if not specified in OPTINS, in set equal to the theoretical wing mean aerodynamic chord. The lateral Page 23 of 67 reference length is set equal to the wing span when it is not user specified. Reference parameters contained in OPTINS must be specified for body-alone configurations since the default reference parameters are based on wing geometry. It is suggested that values near the magnitude of body maximum cross-sectional area be used for the reference area and body maximum diameter for the longitudinal and lateral reference lengths. The output format generally provides at least three significant digits in the solution when user specified reference parameters are of the same order of magnitude as the default reference parameters. If the user specifies reference parameters that are orders of magnitude different from the wing area or aerodynamic chord, some output data can overflow the output format or print only zeros. This may happen in rare instances and would require readjustment of the reference parameters.

IV. DATCOM NAME LISTS

First, we input the CASEID on the first line:

CASEID CESSNA 316

Every piece of data that defines the flight characteristics and geometry of the aircraft is contained in name lists:

- FLTCON - defines the flight conditions
- SYNTHS - locates the cg, wing, horizontal tail, and vertical tail with respect to a reference line
- BODY - defines the body geometry
- WGPLNF - defines the wing planform geometry
- HTPLNF - defines the horizontal tail geometry
- VTPLNF - defines the vertical tail geometry

1. *THE FLTCON NAMELIST:*
   defines the flight conditions such as Mach number(s), altitude(s), and angle of attacks to be analyzed We will use the following variables from the FLTCON namelist:
   - NMACH - number of Mach numbers to be run.
   - MACH - the aformentioned Mach numbers to be run.
   - NALPHA - the number of angles of attack to test.
   - ALSCHD - the schedule of angles of attack.,
   - NALT - number of altitudes to run.
   - ALT - the altitudes to run.
   - WT - the weight of the aircraft.
   - LOOP - we will set to 1.

2. THE SYNTHS NAMELIST
   The SYNTHS (Synthesis) namelist is very important because it sets up the c.g. location as well as the position of the wing and tail surfaces. The following variables from the SYNTHS namelist will be used:
   - XCG - the horizontal position of the c.g.
   - ZCG - the vertical position of the c.g. with respect to the reference line.
   - XW - the horizontal position of the apex of the wing.
   - ZW - the vertical position of the wing apex wrt the reference line.
   - ALIW - the incidence of the wing in degrees.
   - XH - the horizontal position of the apex of the horizontal tail.
   - ZH - the vertical position of the horiz. tail apex wrt the reference line.
   - ALIH - incidence of the horizontal tail.
   - XV - the horizontal position of the apex of the vertical tail.
   - ZV - the vertical position of the vertical tail apex wrt the reference line.

3. THE BODY NAME LIST
   The variables of the name list BODY that we will use are:
   - NX - number of body stations
   - X - horizontal distance of each station
   - S – cross-sectional area at each station

4. THE WGPLNF NAME LIST
   The following are the variables we will use in defining the wing:
   - CHRDTP - the chord’s length at the wing’s tip.
   - SSPNOP - the "Semi-Span outboard panel.”
   - SSPNE - the "exposed" semi-span; this dimension is from the side of the fuselage to the tip chord.

- SSPN - the theoretical semi-span, this dimension is from the root chord to the tip chord.
- CHRDBP - the chord at the breakpoint between the inboard and outboard panel CHRDR - the chord's length at the wing's root.
- SAVSI - the sweep of the wing at the inboard panel (refer to the manual).
- SAVSO - the sweep of the wing at the outboard panel.

5. THE HTPLNF NAME LIST:
   In the same way as the wing
6. THE VTPLNF NAME LIST:
   In the same way, the wing
7. AIRFOIL DESIGNATIONS
   Detect the airfoil type
8. TERMINATING THE FILE:
   We will use three commands:
   - DIM FT - specifies that all of the dimensions were given in feet, and all out the output should be in "English" units
   - BUILD - show the data for all of the components. not just the aircraft
   - PLOT - generate a plot file (for013.dat) to input into the MATLAB plotting program

V. DATCOM INPUTS

To write Datcom code, we should arrange some steps First, we use the inventor to draw the plane and take the plane without wings and tails (body only) as shown in figure 1:

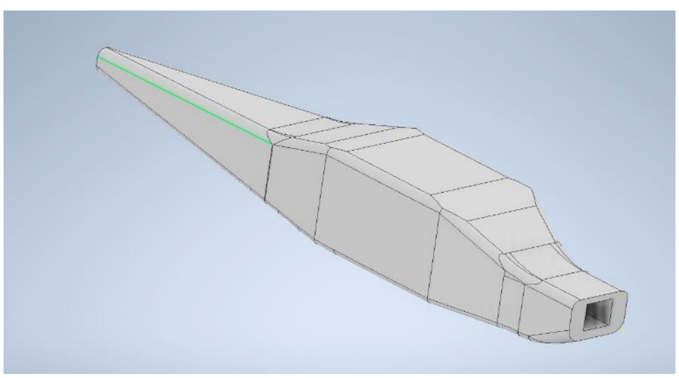


Figure 1:shows the 3d drawing unwinged plane

Then, we divide the drawing part into 20 cross-sections known areas with equi-separated distances as shown in figure 2

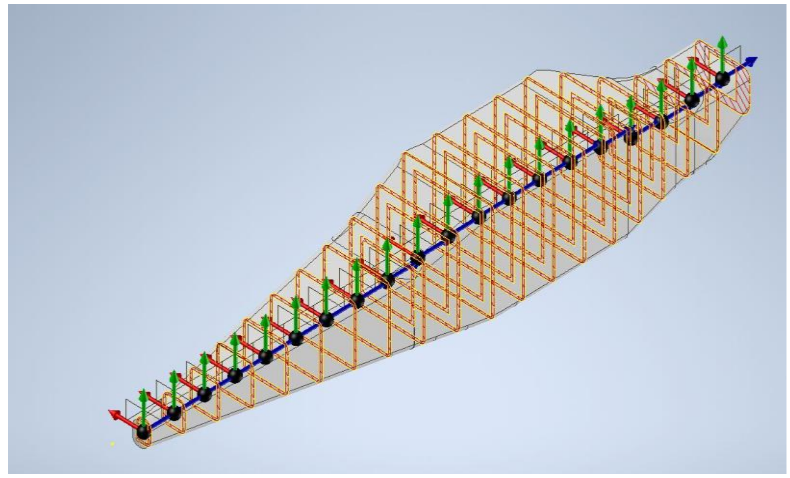
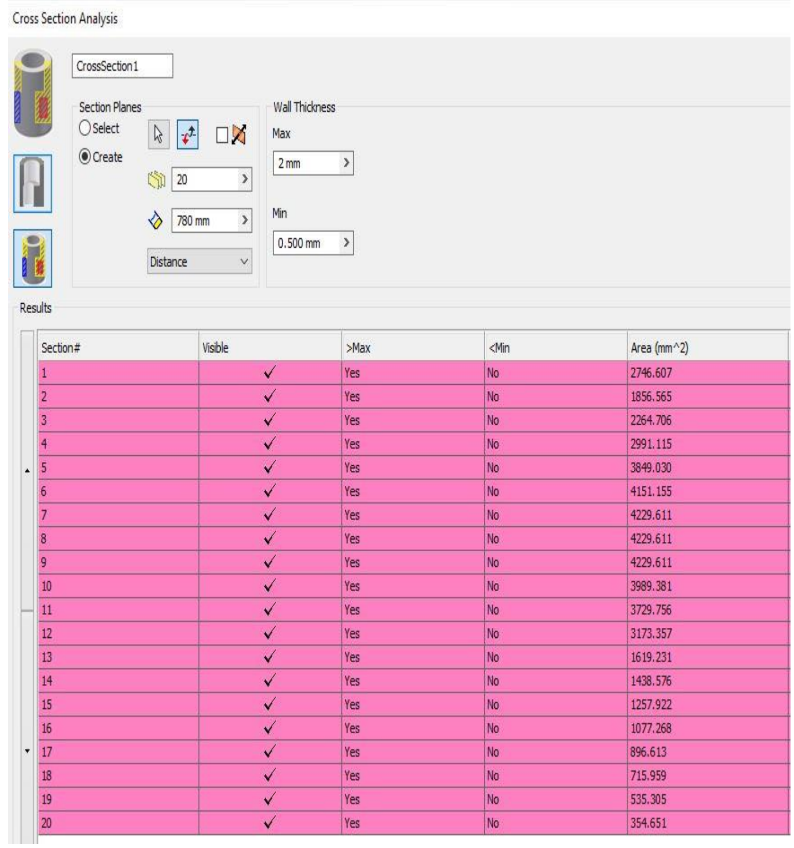


Figure 2:shows the plane dividing into sections with equal distances between them

Then we use inventor to shows the number of crosssections and the areas of each section as shown in figure 3:



Section#	Visible	>Max	<Min	Area (mm^2)
1	✓	Yes	No	2746.607
2	✓	Yes	No	1856.565
3	✓	Yes	No	2264.706
4	✓	Yes	No	2991.115
5	✓	Yes	No	3849.030
6	✓	Yes	No	4151.155
7	✓	Yes	No	4229.611
8	✓	Yes	No	4229.611
9	✓	Yes	No	4229.611
10	✓	Yes	No	3989.381
11	✓	Yes	No	3729.756
12	✓	Yes	No	3173.357
13	✓	Yes	No	1619.231
14	✓	Yes	No	1438.576
15	✓	Yes	No	1257.922
16	✓	Yes	No	1077.268
17	✓	Yes	No	896.613
18	✓	Yes	No	715.959
19	✓	Yes	No	535.305
20	✓	Yes	No	354.651

Figure 3:shows the sections areas

Then, we now can write the datcom code by right click and choose datcom input from new list and right click on the new datcom to edit with notepad++ as shown in figure 4:

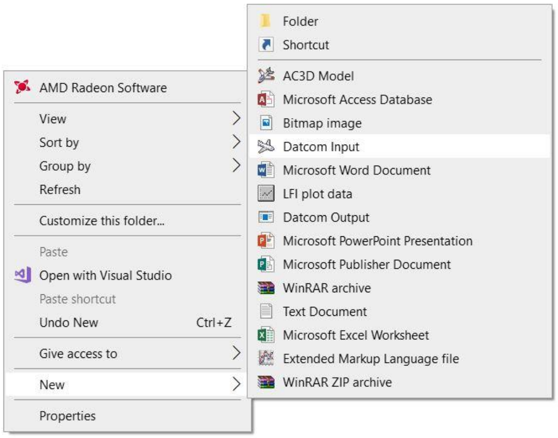


Figure 4:shows how to make datcom input file

We here start to identify the id of plane and start to write the code as we see in the paper by entering the data of plane starting from flight conditions, location of c.g of plane parts, body wings and tail characteristics and build the program as shown in figures 5:

```
DIM FT
DERIV RAD
DAMP
 $FLTCON WT=2205.29, LOOP=3.0, NMACH=1.0, MACH(1)=0.16,
          NALT=1.0, ALT(1)=5000.0, NALPHA=8.0,
          ALSCHD(1)=-2.5,0.0,1.0,2.43,4.9,7.5,10.0,12.5$
 $SYNTHS XCG=7.29, ZCG=3.25, XW=6.05, ZW= 6.80, ALIW= 1.5,
        XH=19.53, ZH= 3.82, ALIH= 0.0, XV=20.26, ZV= 4.25,
        SCALE=1.0, VERTUP=.TRUE.$
 $BODY NX=20.0, ITYPE=2.0, METHOD=2.0,
      X(1)=0.34,0.85,1.80,2.21,3.82,5.01,5.73,6.16,8.49,10.15,11.55,
      12.95,14.39,15.92,17.75,19.27,20.76,22.29,23.69,24.84,
      S(1)=7.63,20.45,21.76,22.88,24.37,28.03,31.54,34.55,35.08,32.20,
      26.38,23.37,19.90,17.51,14.92,12.13,10.00,6.99,4.79,0.65,
      P(1)=17.61,18.76,18.46,18.74,20.46,21.76,22.80,22.91,22.22,19.99,
      18.69,18.04,17.59,17.08,16.57,16.32,16.19,16.05,15.98,
      R(1)=0.57,1.60,1.80,1.91,2.11,2.19,2.32,2.42,2.45,2.27,2.06,1.88,
      1.70,1.44,1.24,1.00,0.82,0.57,0.39,0.05,
      ZU(1)=4.84,5.26,5.31,5.35,5.35,6.20,6.71,7.05,6.96,6.71,5.77,
      5.14,4.97,4.92,4.80,4.67,4.54,4.42,4.33,4.25,
      ZL(1)=3.74,2.89,2.38,2.29,2.00,1.95,1.95,2.04,2.17,2.34,2.45,2.55,
      2.72,2.80,2.89,3.01,3.18,3.31,3.57,3.74$
 $WGPLNF CHRDR=5.3332, CHRDBP=5.3332, CHRDTP=3.708, SSPN=18.0,
         SSPNE=15.59,  SSPNOP=9.651,  SAVSI=0.0,    SAVSO=3.0, CHSTAT=0.0,
         TWISTA=-3.0,  DHDADI=1.7333, DHDADO=1.7333,TYPE=1.0$
NACA-W-4-2412
NACA-V-4-0009
 $VTPLNF CHRDR=4.58, CHRDTP=2.12, SSPN=4.45, SSPNE=4.25,
         SAVSI=35.0, CHSTAT=0.25, TYPE=1.0$
NACA-H-4-0012
 $HTPLNF CHRDR=4.55, CHRDTP=2.52, SSPN= 5.67, SSPNE=4.92,
         SAVSI= 9.0, CHSTAT=0.0, TWISTA=0.0, DHDADI=0.0, TYPE=1.0$
 $SYMFLP FTYPE=1.0, SPANFI=0.75, SPANFO=5.667, CHRDFI=1.83, CHRDFO=0.87,
         NTYPE=1.0, DELTA=9.0,
         DELTA(1)=-20.0,-10.0,-5.0,0.0,7.5,15.0,20.0,25.0,30.0$
CASEID TOTAL: Cessna C-316 Aircraft
```

Figure 5: The code for Cessna 316

And by saving this code and open the datcom input file, we can see the 3d of our plane. This is a 3D view at figure 6.

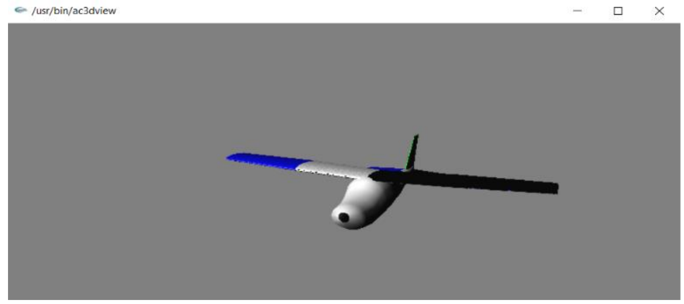


Figure 6:3D view of Cessna316

We notice that all needed files are self-created (datcom output, datcom 3D model and other plots that describe the aerodynamic and stability characteristics).

Flight conditions of Cessna 316 can be also seen in datcom output as shown in figures 7, 8.

We finally take the aerodynamic coefficients and stability characteristics as shown in figures 9, 10.

We take the notepad file in matlab code for aerodynamic model to use in equations of dynamic model.

VI. Conclusion and Future Work

We now touched that how simple Datcom calculates the aerodynamic coefficients and stability characteristics, one also showed the aerodynamic model and how the coefficient affects the movement of the vehicle; we noticed that Datcom data uses some other software like Inventor or Solid works and any compiler like notepad++, one finally showed the coding of data input and expressed the results of aerodynamic coefficient file that we use in Matlab in dynamic model or the 3d view of the vehicle.

In the future, we wish to use another modeling aerodynamic modeling that is a little more complex but gives better results, like wind tunnel testing.

VII. References

[1] RANDAL W. BEARD and TIMOTHY W. McLain, “Small Unmanned Aircraft”, Theory and Practice,2012.

[2] Finn Jensen and Daniel René Hagen Pedersen, “Autonomous Aircraft”, A nonlinear approach,2005.

[3] DATCOM Beginner’s Tutorial.

[4] McDonnell Douglas Astronautics Company, St. Louis Division and St Louis Missouri 63166. “THE USAF STABILITY AND CONTROL DATCOM Volume I, User’s Manual”.

VIII. FIGURES

```
AUTOMATED STABILITY AND CONTROL METHODS PER APRIL 1976 VERSION OF DATCOM
                        WING SECTION DEFINITION
         IDEAL ANGLE OF ATTACK =    .25757 DEG.

      ZERO LIFT ANGLE OF ATTACK =  -1.87965 DEG.

          IDEAL LIFT COEFFICIENT =    .25602

ZERO LIFT PITCHING MOMENT COEFFICIENT =   -.05087

       MACH ZERO LIFT-CURVE-SLOPE =    .09617 /DEG.

             LEADING EDGE RADIUS =    .01587 FRACTION CHORD

      MAXIMUM AIRFOIL THICKNESS =    .12000 FRACTION CHORD

                       DELTA-Y =   3.16898 PERCENT CHORD

  MACH=  .1600 LIFT-CURVE-SLOPE =    .09717 /DEG.      XAC =    .25831
AUTOMATED STABILITY AND CONTROL METHODS PER APRIL 1976 VERSION OF DATCOM
                   HORIZONTAL TAIL SECTION DEFINITION
         IDEAL ANGLE OF ATTACK =    .00000 DEG.

      ZERO LIFT ANGLE OF ATTACK =    .00000 DEG.

          IDEAL LIFT COEFFICIENT =    .00000

ZERO LIFT PITCHING MOMENT COEFFICIENT =    .00000

       MACH ZERO LIFT-CURVE-SLOPE =    .09596 /DEG.

             LEADING EDGE RADIUS =    .01587 FRACTION CHORD

      MAXIMUM AIRFOIL THICKNESS =    .12000 FRACTION CHORD

                       DELTA-Y =   3.16898 PERCENT CHORD
```

Figure 7: Flight conditions of CESSNA 316

```
  MACH=  .1600 LIFT-CURVE-SLOPE =    .09700 /DEG.      XAC =    .25867
AUTOMATED STABILITY AND CONTROL METHODS PER APRIL 1976 VERSION OF DATCOM
                   VERTICAL TAIL SECTION DEFINITION
         IDEAL ANGLE OF ATTACK =    .00000 DEG.

      ZERO LIFT ANGLE OF ATTACK =    .00000 DEG.

          IDEAL LIFT COEFFICIENT =    .00000

ZERO LIFT PITCHING MOMENT COEFFICIENT =    .00000

       MACH ZERO LIFT-CURVE-SLOPE =    .09830 /DEG.

             LEADING EDGE RADIUS =    .00893 FRACTION CHORD

      MAXIMUM AIRFOIL THICKNESS =    .09000 FRACTION CHORD

                       DELTA-Y =   2.37673 PERCENT CHORD
```

Figure8: Complementary of flight conditions

```
            MACH=  .1600 LIFT-CURVE-SLOPE =    .09942 /DEG.      XAC =    .25662
                 AUTOMATED STABILITY AND CONTROL METHODS PER APRIL 1976 VERSION OF DATCOM
                         CHARACTERISTICS AT ANGLE OF ATTACK AND IN SIDESLIP
                        WING-BODY-VERTICAL TAIL-HORIZONTAL TAIL CONFIGURATION
                                   TOTAL: Cessna C-316 Aircraft

----------------------- FLIGHT CONDITIONS ------------------------       -------------- REFERENCE DIMENSIONS ------------
 MACH    ALTITUDE   VELOCITY    PRESSURE    TEMPERATURE     REYNOLDS          REF.     REFERENCE LENGTH   MOMENT REF. CENTER
NUMBER                                                       NUMBER           AREA      LONG.     LAT.     HORIZ     VERT
            FT       FT/SEC     LB/FT**2       DEG R          1/FT            FT**2      FT        FT        FT        FT
  .160    5000.00    175.52   1.7609E+03     500.843      9.8411E+05         176.310    4.955    36.000     7.290     3.250
                                                              -------------------DERIVATIVE (PER RADIAN)-------------------
 ALPHA     CD       CL        CM       CN       CA       XCP       CLA         CMA         CYB         CNB         CLB

  -2.5    .030    -.083     .0314    -.084     .026    -.375   5.163E+00   -3.210E-01   -2.697E-01   -6.998E-03   -1.935E-01
    .0    .030     .148     .0070     .148     .030     .048   5.408E+00   -6.420E-01                              -2.013E-01
   1.0    .032     .243    -.0047     .244     .028    -.019   5.539E+00   -7.195E-01                              -2.045E-01
   2.4    .036     .384    -.0243     .386     .020    -.063   5.745E+00   -8.533E-01                              -2.093E-01
   4.9    .048     .639    -.0663     .640    -.007    -.104   6.024E+00   -1.121E+00                              -2.179E-01
   7.5    .067     .918    -.1241     .919    -.053    -.135   6.249E+00   -1.440E+00                              -2.275E-01
  10.0    .093    1.195    -.1939    1.193    -.116    -.163   6.158E+00   -1.770E+00                              -2.368E-01
  12.5    .123    1.455    -.2786    1.447    -.195    -.192   5.795E+00   -2.110E+00                              -2.452E-01
                                    ALPHA     Q/QINF    EPSLON  D(EPSLON)/D(ALPHA)

                                    -2.5      1.000     -.180        .484
                                      .0      1.000     1.030        .484
                                     1.0      1.000     1.513        .483
                                     2.4      1.000     2.203        .480
                                     4.9      1.000     3.380        .471
                                     7.5      1.000     4.589        .454
                                    10.0      1.000     5.697        .421
                                    12.5      1.000     6.694        .399
```

Figure 9: Aerodynamic coefficients for input angles of attack

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                 AUTOMATED STABILITY AND CONTROL METHODS PER APRIL 1976 VERSION OF DATCOM
                                       DYNAMIC DERIVATIVES
                        WING-BODY-VERTICAL TAIL-HORIZONTAL TAIL CONFIGURATION
                                   TOTAL: Cessna C-316 Aircraft

----------------------- FLIGHT CONDITIONS ------------------------       -------------- REFERENCE DIMENSIONS ------------
 MACH    ALTITUDE   VELOCITY    PRESSURE    TEMPERATURE     REYNOLDS          REF.     REFERENCE LENGTH   MOMENT REF. CENTER
NUMBER                                                       NUMBER           AREA      LONG.     LAT.     HORIZ     VERT
            FT       FT/SEC     LB/FT**2       DEG R          1/FT            FT**2      FT        FT        FT        FT
  .160    5000.00    175.52   1.7609E+03     500.843      9.8411E+05         176.310    4.955    36.000     7.290     3.250
                                              DYNAMIC DERIVATIVES (PER RADIAN)
          -------PITCHING-------   -----ACCELERATION------  --------------ROLLING--------------  --------YAWING--------
  ALPHA       CLQ          CMQ          CLAD        CMAD        CLP         CYP         CNP         CNR         CLR

  -2.50   7.026E+00   -5.498E+00    2.077E+00  -5.667E+00  -4.429E-01  -4.170E-02   2.969E-03  -2.666E-02  -1.086E-02
    .00                             2.077E+00  -5.666E+00  -4.748E-01  -4.627E-02  -1.080E-02  -2.746E-02   2.993E-02
   1.00                             2.074E+00  -5.659E+00  -4.870E-01  -4.818E-02  -1.626E-02  -2.806E-02   4.707E-02
   2.43                             2.061E+00  -5.624E+00  -5.025E-01  -5.098E-02  -2.408E-02  -2.925E-02   7.230E-02
   4.90                             2.022E+00  -5.517E+00  -5.241E-01  -5.606E-02  -3.778E-02  -3.226E-02   1.176E-01
   7.50                             1.949E+00  -5.317E+00  -5.399E-01  -6.166E-02  -5.260E-02  -3.686E-02   1.670E-01
  10.00                             1.808E+00  -4.932E+00  -5.227E-01  -6.747E-02  -6.921E-02  -4.273E-02   2.155E-01
  12.50                             1.713E+00  -4.673E+00  -4.770E-01  -7.265E-02  -8.582E-02  -4.925E-02   2.598E-01
*** VEHICLE WEIGHT =   2205.29 LB.
*** LEVEL FLIGHT LIFT COEFFICIENT =  .39639
```

Figure 10: Aerodynamic coefficients and stability characteristics