Using Athena Vortex Lattice (AVL)

MAE 457 – Spring 2019

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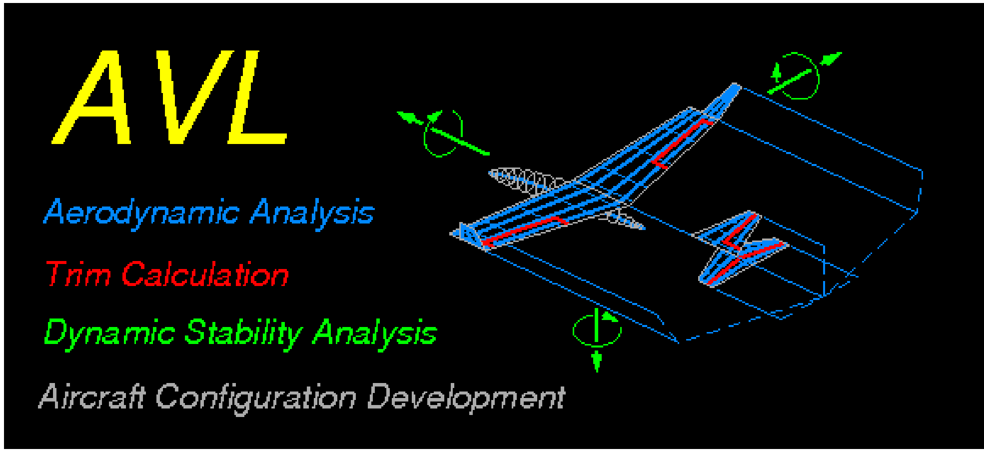
AVL automates tedious calculations

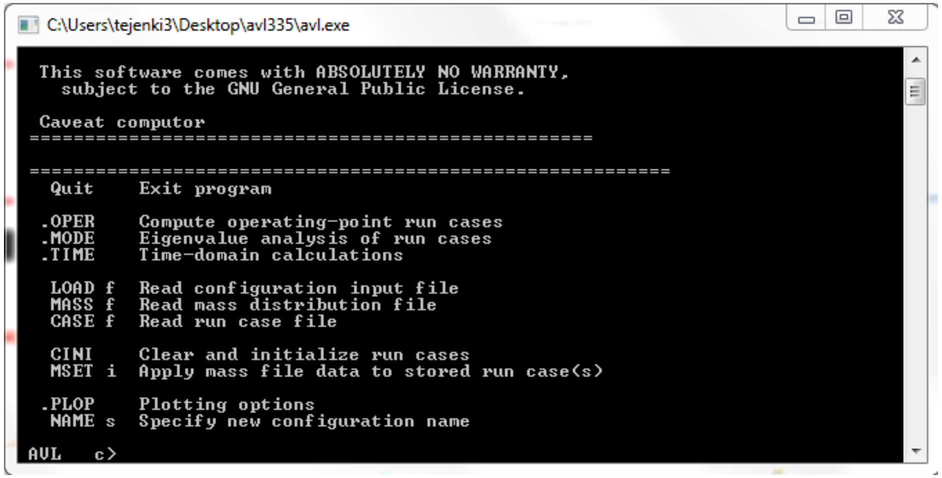
- Used for aerodynamic and flight-dynamic analysis
- Employs "extended vortex lattice model"
- Input wing/airfoil geometry, controls
- Outputs operating variables and stability derivatives



Download at:
http://web.mit.edu/drela/Public/web/avl/

…But AVL isn't all encompassing

- Uses command line interface
  - Use Sublime Text 2, Notepad++, etc. to code, then execute with AVL

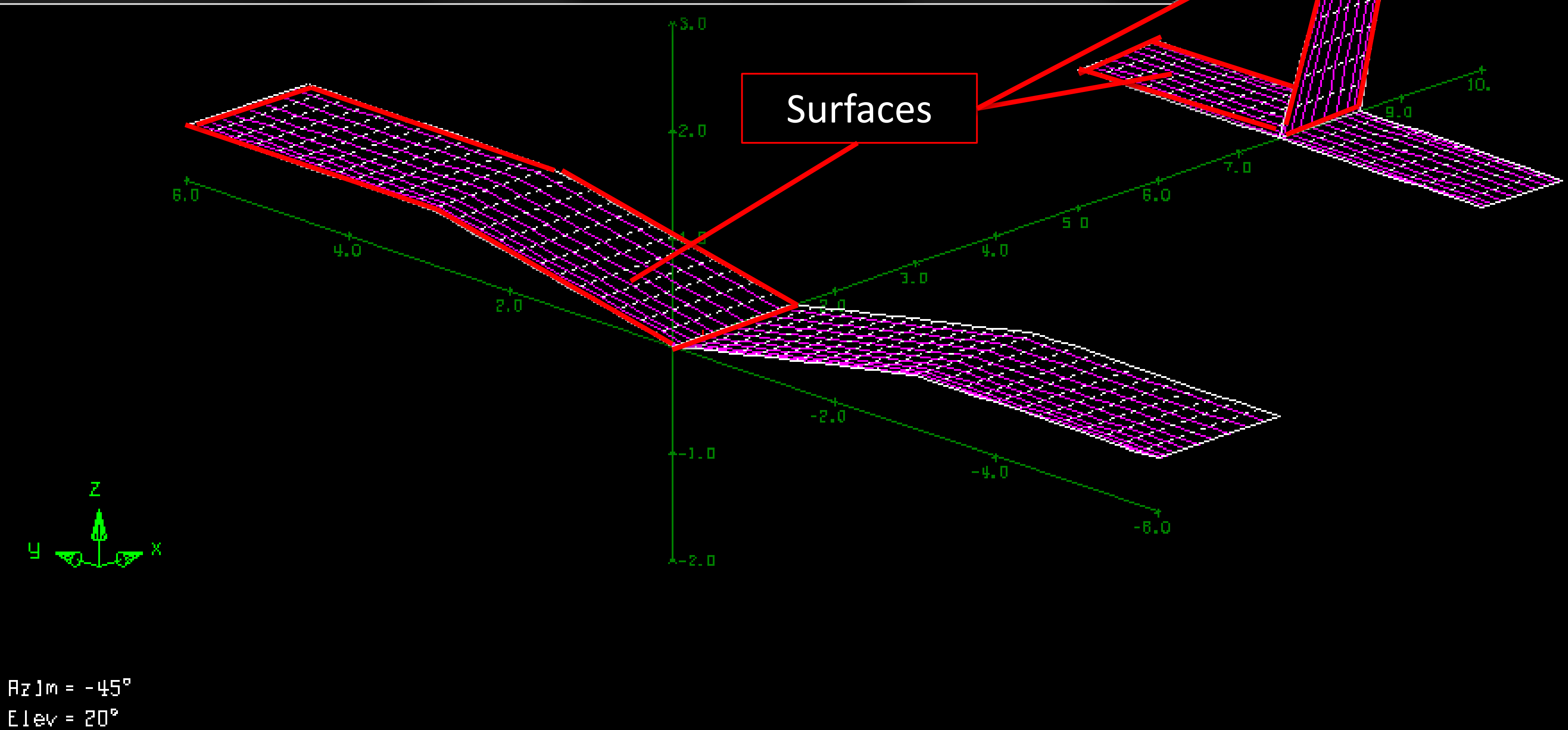


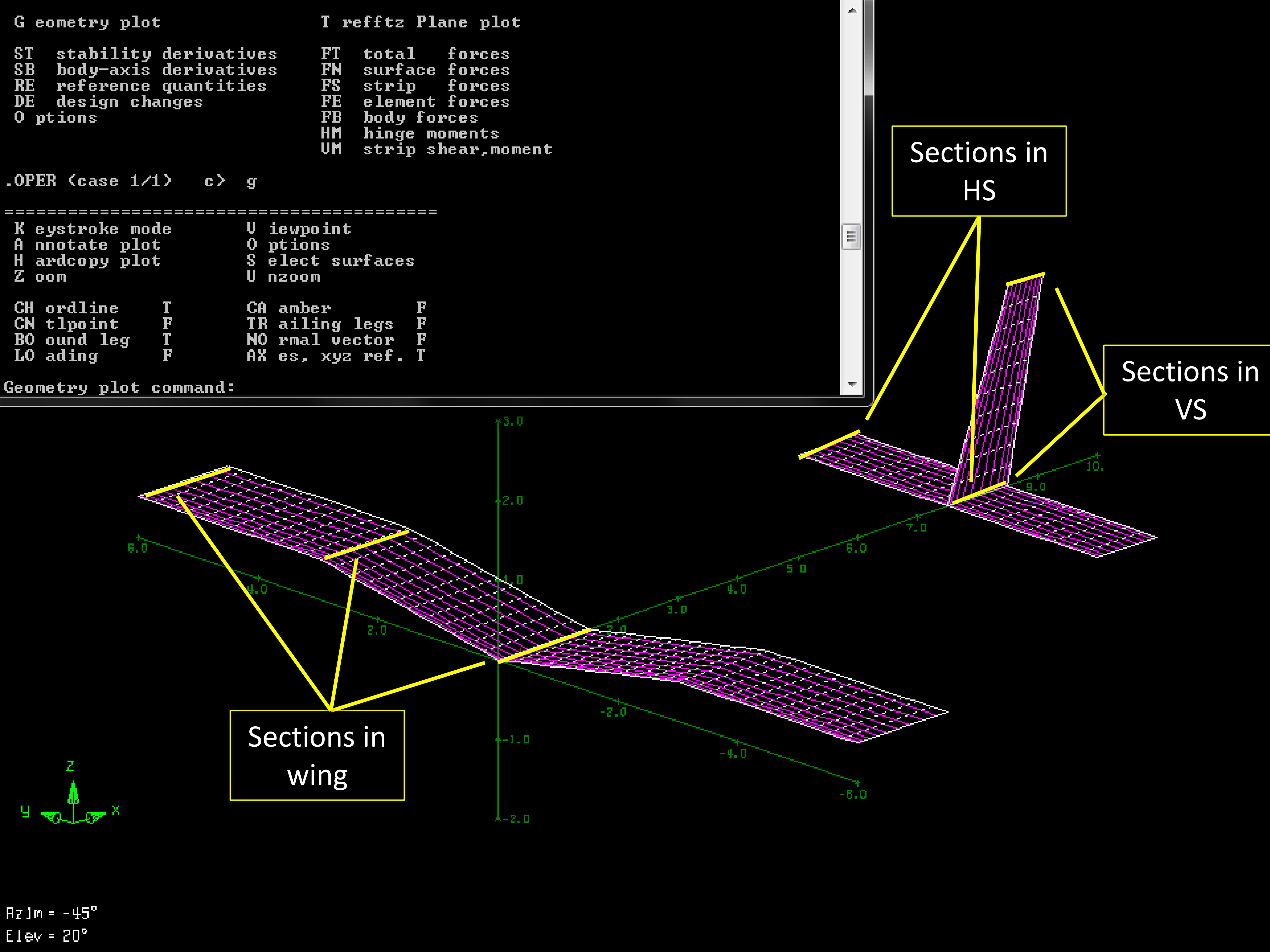
✓	✗
Swept wing geometries	Aspect ratio < 4
Minimal fuselage effects (we will ignore fuselage entirely)	Heavy or large fuselage
Subsonic	Supersonic
Steady aerodynamics	Unsteady aerodynamics

Building your aircraft with a .AVL file

- Example aircraft code provided (image on next slide)
- Code is divided into modules (within a single file)
  - “**Header**” defines reference values
  - “**Surfaces**” are defined (wings, horizontal stabilizer, vertical stabilizer)
  - “**Sections**” are then defined within each surface
  - “**Controls**” can be added to the sections
- Only define half of the aircraft, and then mirror
- Stay organized – use # to comment

```
 G eometry plot                 T refftz Plane plot

 ST  stability derivatives      FT  total   forces
 SB  body-axis derivatives      FN  surface forces
 RE  reference quantities       FS  strip   forces
 DE  design changes             FE  element forces
 O ptions                       FB  body forces
                                HM  hinge moments
                                VM  strip shear,moment

.OPER (case 1/1)   c>  g

=========================================
 K eystroke mode        V iewpoint
 A nnotate plot         O ptions
 H ardcopy plot         S elect surfaces
 Z oom                  U nzoom

 CH ordline     T       CA amber        F
 CN tlpoint     F       TR ailing legs  F
 BO ound leg    T       NO rmal vector  F
 LO ading       F       AX es, xyz ref. T

Geometry plot command:
```




G eometry plot
T refftz Plane plot
ST stability derivatives
SB body-axis derivatives
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K eystroke mode
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U nzoom
CH ordline T
CN tlpoint F
BO ound leg T
LO ading F
CA amber F
TR ailing legs F
NO rmal vector F
AX es, xyz ref. T
Geometry plot command:
Sections in HS
Sections in VS
Sections in wing
Azim = -45°
Elev = 20°

Input files

- AVL works with three input files, all in plain text format. Ideally these all have a common arbitrary prefix "xxx", and the following extensions:

- xxx.avl required main input file defining the configuration geometry
- xxx.mass optional file giving masses and inertias, and dimensional units
- xxx.run optional file defining the parameter for some number of run cases

Getting started with an input file

- Create a new text file, and save as xxx.avl
  - Alternatively, use *open with* your preferred text editor
- Files consist of keywords and associated data
  - Order matters!
- We will run through code, and then execute an example

```
MAE 457 Example_Airplane
#Mach
 0.0
#IYsym   IZsym   Zsym
 0       0       0.0
#Sref    Cref    Bref
18      1.5       12
#Xref    Yref    Zref
0.375     0.0     0
#
#===========================
```

Header defines reference values

- **Mach**: default freestream Mach number for Prandtl-Glauert correction
- **XXsym**: used to define symmetry (1 or 0), leave as 0
- **Sref**: reference area for CL, Cd, Cm, etc.
- **Cref**: reference chord for Cm
- **Bref**: reference span for Cl, Cn
- **X, Y ,Zref**: where moment and rotation rates are defined, *must be CG for trim calculations!*

```
MAE 457 Example_Airplane
#Mach
 0.0
#IYsym   IZsym   Zsym
 0       0       0.0
#Sref    Cref    Bref
18      1.5       12
#Xref    Yref    Zref
0.375     0.0     0
#
#==========================
```

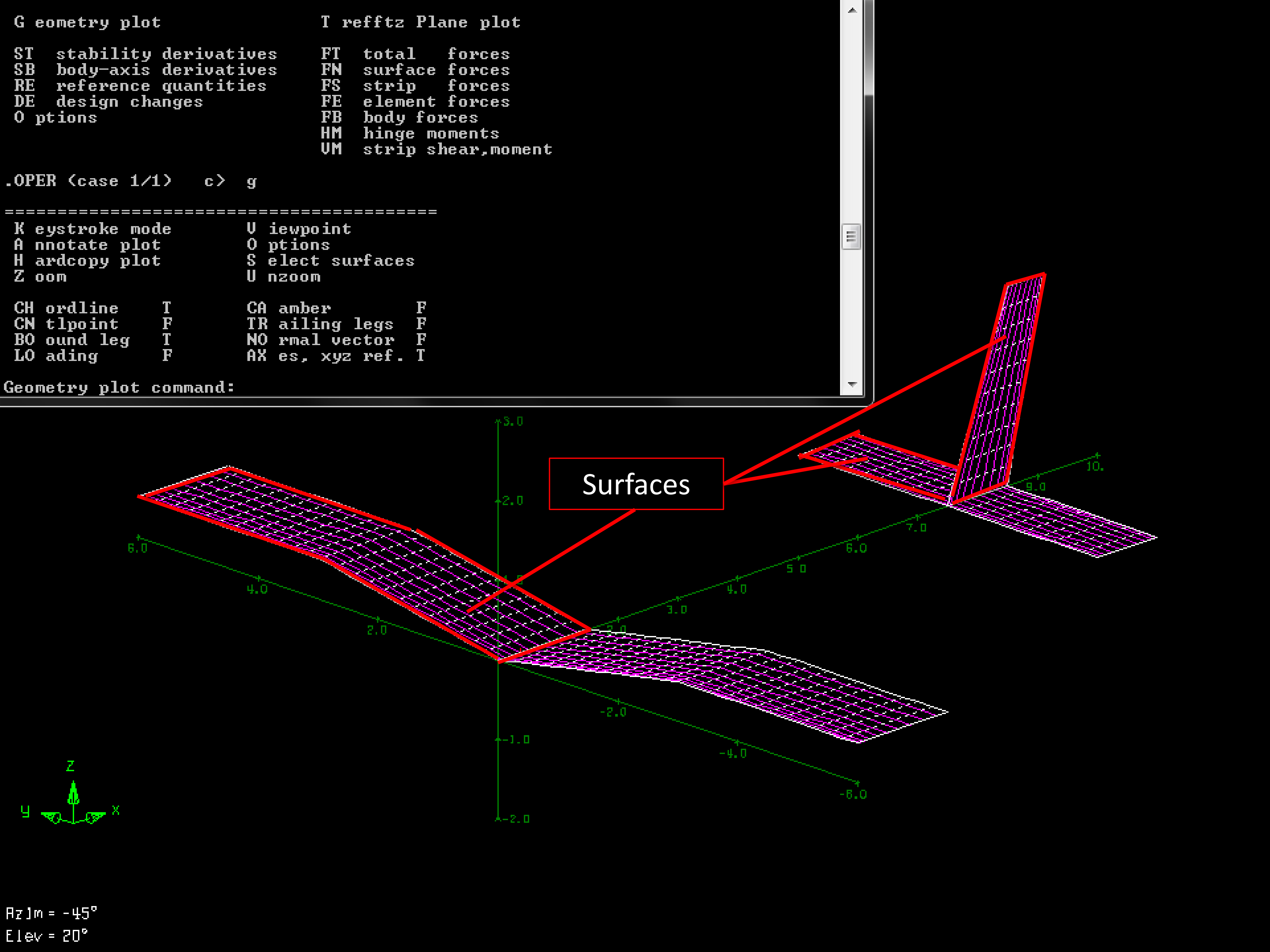
Surfaces define overall geometry

- **SURFACE** tells program a new surface is being declared
- **Main Wing** is user defined name
- **Nchordwise** defines number of chordwise panels until the next section (optional)
- **YDUPLICATE** mirrors the surface (remember, we left Xzsym=0)
- **TRANSLATE** allows relocation without changing section's values

```
SURFACE
Main Wing
#Nchordwise  Cspace
10           2.0
#
YDUPLICATE
0.0
#
TRANSLATE
0.0 0.0 0.0
#
ANGLE
0.0
#
#--------------------
```

Input file (NOWAKE, NOALBE, NOLOAD)

- The **NOWAKE** keyword specifies that this surface is to NOT shed a wake, so that its strips will not have their Kutta conditions imposed.
- The **NOLOAD** keyword specifies that the force and moment on this surface is to NOT be included in the overall forces and moments of the configuration.
- The **NOALBE** keyword specifies that this surface is unaffected by freestream direction changes specified by the alpha,beta angles and p,q,r rotation rates.



G eometry plot
T refftz Plane plot
ST stability derivatives
SB body-axis derivatives
RE reference quantities
DE design changes
O ptions
FT total forces
FN surface forces
FS strip forces
FE element forces
FB body forces
HM hinge moments
VM strip shear,moment
.OPER (case 1/1) c> g
==
K eystroke mode
A nnotate plot
H ardcopy plot
Z oom
V iewpoint
O ptions
S elect surfaces
U nzoom
CH ordline T
CN tlpoint F
BO ound leg T
LO ading F
CA amber F
TR ailing legs F
NO rmal vector F
AX es, xyz ref. T
Geometry plot command:
Surfaces
Azim = -45°
Elev = 20°

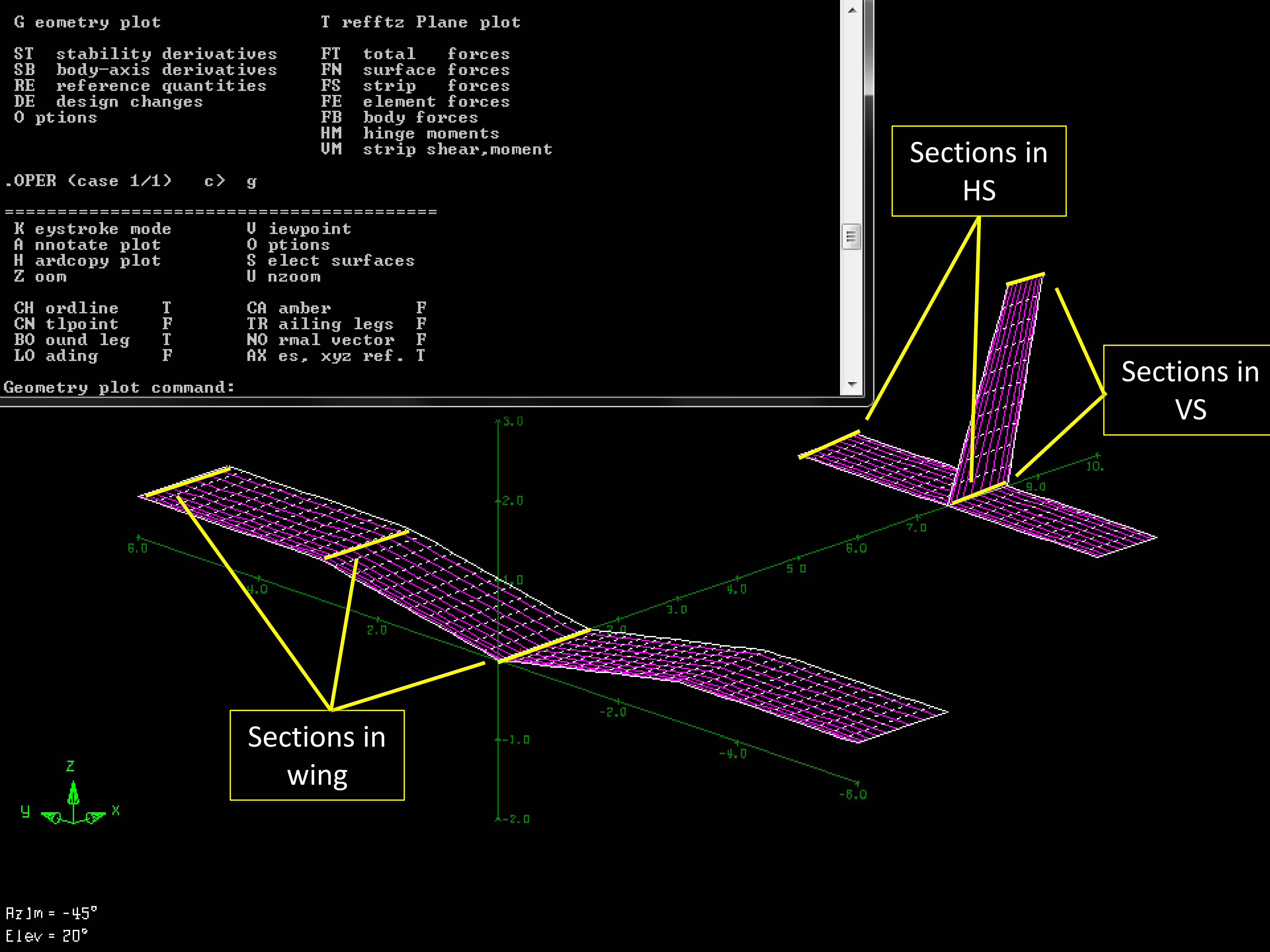
Sections define surface geometry

- **Sections** are airfoil-section chord lines, defined at various spanwise locations
- **(Xle,Yle,Zle)**: section's leading edge location
- **Chord**: chord length, trailing edge = (Xle+Chord,Yle,Zle)
- **Ainc**: incidence angle
- **Nspanwise**: number of spanwise panels (white lines)
- **Sspace**: controls panel spacing (0 is linear spacing)
- **NACA**: sets 4-digit airfoil shape
- Can also use **AFILE** with a .dat file imported from XFOIL

```
SECTION
#Xle      Yle     Zle      Chord    Ainc   Nspanwise   Sspace
0         0.0     0        1.5      0.     12           0

NACA
4412

```


G eometry plot
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NO rmal vector F
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Geometry plot command:
Sections in HS
Sections in VS
Sections in wing
Azim = -45°
Elev = 20°

Define control surfaces

- **Name**: Control variable (flap, aileron, elevator, rudder)
- **Cgain**: Deflection gain, units: degrees deflection/control variable
- **Xhinge:** x/c location of hinge, -1<Xhinge<1
  - If negative, control surface extent is 0..-Xhinge (LE)
  - If positive, control surface extent is Xhinge..1 (TE)
- **HingeVec:** defines the axis the control rotates about
- **SgnDup:** sign of deflection for duplicated surface
  - Elevator SgnDup=+1, aileron SgnDup=-1
- Define controls at beginning and ending sections

```
#Cname    Cgain   Xhinge   HingeVec      SgnDup
CONTROL
flap      1.0     0.75     0.0 0.0 0.0    1.0
#Cname    Cgain   Xhinge   HingeVec      SgnDup
CONTROL
aileron    1.0     0.80     0.0 0.0 0.0    -1.0
#
```

Running the input file in AVL

- Two options for loading the file (make sure file is in path):
  - Drag and drop xxx.avl onto avl.exe, OR
  - Run avl.exe, type ***load xxx.avl***
- After loaded, use ***OPER*** to enter operating-point mode
- Next, use ***X*** to e***X***ecute the run case
- Various commands can now be executed:
  - ***G*** to create visual of defined geometry
  - ***M*** to modify parameters (change CG, mass, air density, g)
    - Default values = 1, must change this!
    - Keep units consistent – if you defined aircraft in m, use kg, kg/m^3, and m/s^2
    - Do not over-constrain, e.g. set alpha OR velocity, not both
  - ***ST*** to create stability derivatives

Other commands to try at your leisure

```
 C1  set level or banked  horizontal flight constraints
 C2  set steady pitch rate (looping) flight constraints
 M odify parameters

"#" select  run case          L ist defined run cases
 +  add new run case          S ave run cases to file
 -  delete  run case          F etch run cases from file
 N ame current run case       W rite forces to file

eX ecute run case             I nitialize variables

 G eometry plot               T refftz Plane plot

 ST  stability derivatives    FT  total   forces
 SB  body-axis derivatives    FN  surface forces
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 DE  design changes           FE  element forces
 O ptions                     FB  body forces
                              HM  hinge moments
                              VM  strip shear,moment
```

- Copy/paste a script to avoid re-typing commands 40 times
- Use MATLAB to iteratively run AVL for various angles of attack

Running multiple cases is tedious. Enter…"Batch Files"

- And whatever the equivalent on Mac is…

- Save instructions as ".run" file.
- AVL will execute these commands exactly as you input them in order.
- Spaces are important! This is how AVL knows to use the enter key.
- Run through commands "manually" first to check.

Load input file

Modify parameters

Modify angle of attack

Calculate stability derivatives and save output

```
LOAD
airplane
OPER
M
M 1000
V 50
G 9.81
D 1.225

a a 2.5
x
st
airplane_ST.out
O

quit
```

Running multiple cases is tedious. Enter…"Batch Files"

- And whatever the equivalent on Mac is…

```
@echo off
del airplane_ST_1.out
avl < airplane_1.run
del airplane_ST_2.out
avl < airplane_2.run
```

.bat file

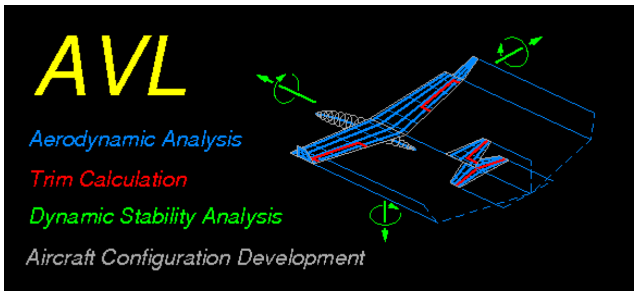
```
LOAD
airplane
OPER
M
M 1000
V 50
G 9.81
D 1.225

a a 2.5
x
st
airplane_ST.out
O

quit
```

.run file

```
C:\Users\AAA\Documents\AVL>airplane.bat
```

Must be in same directory as avl.exe….(unless you've added it to your path)

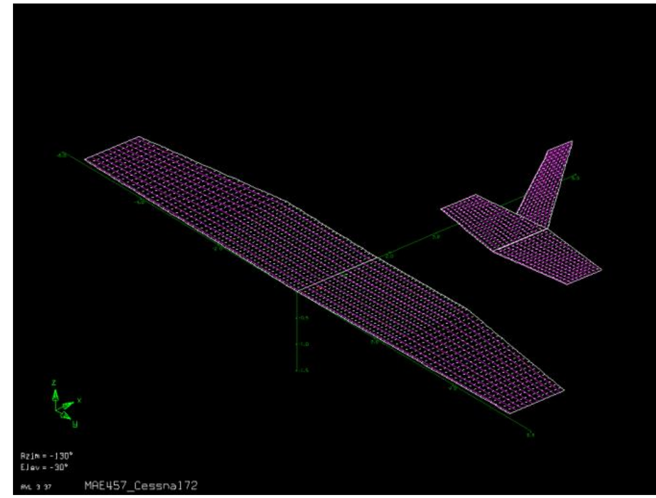
You can also run AVL through MATLAB for ultimate convenience (and coolness)

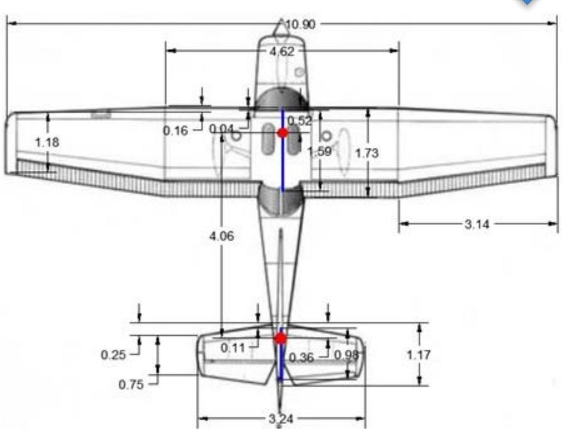


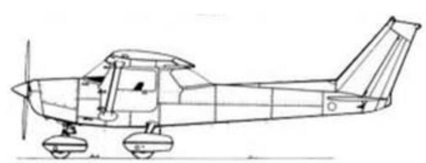

```
Command Window
>> system('avl.exe')

 ==================================================
  Athena Vortex Lattice  Program      Version  3.37
  Copyright (C) 2002   Mark Drela, Harold Youngren

  This software comes with ABSOLUTELY NO WARRANTY,
    subject to the GNU General Public License.

  Caveat computor
 ==================================================

 ==========================================================
   Quit    Exit program

  .OPER    Compute operating-point run cases
  .MODE    Eigenvalue analysis of run cases
  .TIME    Time-domain calculations

   LOAD f  Read configuration input file
   MASS f  Read mass distribution file
   CASE f  Read run case file

   CINI    Clear and initialize run cases
   MSET i  Apply mass file data to stored run case(s)

  .PLOP    Plotting options
   NAME s  Specify new configuration name

 AVL   c>
```

- Run analyses and post-process data all in the same place
- Same principles apply for run files and batch files
- Write your own function to automatically generate .avl files for you

Example: Cessna 172







- Aerodynamic Center Location

- m.a.c Location and Length

Cessna 172 Example: δ_e trim vs velocity

- Define flight parameters

```
.OPER (case 1/1)   c>  m

    Parameters of run case 1/1:   -unnamed-
     B  bank       =  0.000      deg
     E  elevation  =  0.000      deg
     MN Mach no.   =  0.000
     V  velocity   =  50.00      Lunit/Tunit
     D  air dens.  =  1.225      Munit/Lunit^3
     G  grav.acc.  =  9.810      Lunit/Tunit^2
     M  mass       =  1111.      Munit
     IX Ixx        =  1.000      Munit-Lunit^2
     IY Iyy        =  1.000      Munit-Lunit^2
     IZ Izz        =  1.000      Munit-Lunit^2
     X  X_cg       = 0.4980      Lunit
     Y  Y_cg       =  0.000      Lunit
     Z  Z_cg       = -.1100      Lunit
     CD CDo        =  0.000
     LA dCL_a      =  0.000
     LU dCL_u      =  0.000
     MA dCM_a      =  0.000
     MU dCM_u      =  0.000

    Enter parameter, value  (or  # - + N )   c>
```

```
LOAD
cessna172
OPER
M
M 1111
V 35.0
G 9.81
D 1.225

d2 rm 0
d3 pm 0
d4 ym 0
c1
x 0.498

X
ST
cessna172_ST_1.out
O

quit
```

Cessna 172 Example: δ_e trim vs velocity

- Define control surface behavior for trim conditions
  - Constrain elevator angle to maintain zero pitching moment, etc.

```
.OPER (case 1/1)   c>  d2

      constraint              value
     - - - - - - - - - - - - - - - - -
      A     alpha         =   0.000
      B     beta          =   0.000
      R     pb/2V         =   0.000
      P     qc/2V         =   0.000
      Y     rb/2V         =   0.000
      C     CL            =   0.000
      S     CY            =   0.000
      RM    Cl roll mom   =   0.000
      PM    Cm pitchmom   =   0.000
      YM    Cn yaw  mom   =   0.000
      D1    flap          =   0.000
   -> D2    aileron       =   0.000
      D3    elevator      =   0.000
      D4    rudder        =   0.000

     Select new  constraint,value  for aileron        c>  rm 0
```

```
LOAD
cessna172
OPER
M
M 1111
V 35.0
G 9.81
D 1.225

d2 rm 0
d3 pm 0
d4 ym 0
c1
x 0.498

X
ST
cessna172_ST_1.out
O

quit
```

Cessna 172 Example: δ_e trim vs velocity

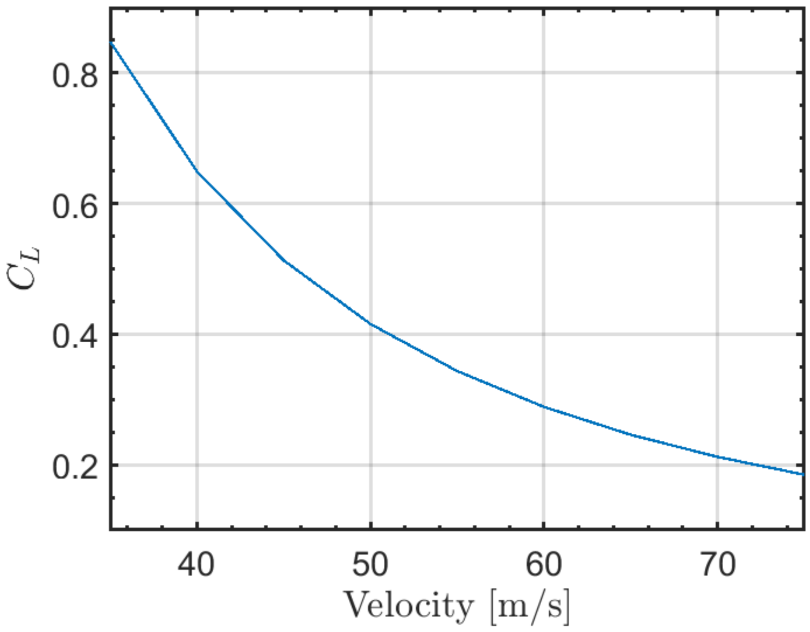
- Use “c1” to set level horizontal flight conditions
  - AVL assigns a lift coefficient based on velocity
  - Change CG location if desired

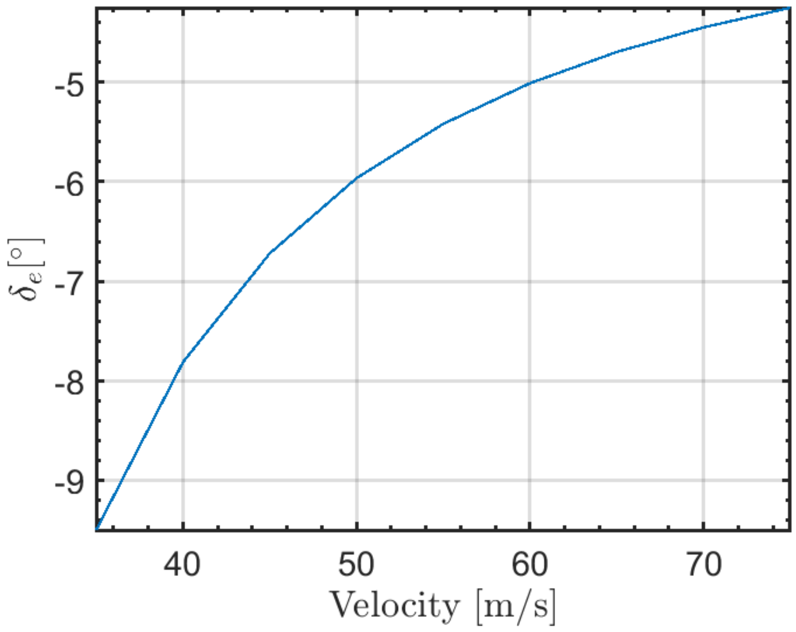
```
.OPER (case 1/1)   c>  c1

      Setting trim CL from current CL constraint

   .. setting new CL for run case  1
   .. setting new turn radius for run case  1
   .. setting new load factor for run case  1

   Setup of trimmed run case 1/1:   -unnamed-
   (level or banked horizontal flight)
   =================================================
    B  bank angle =  0.000      deg
    C  CL         = 0.4155
    V  velocity   =  50.00      Lunit/Tunit
    M  mass       =  1111.      Munit
    D  air dens.  =  1.225      Munit/Lunit^3
    G  grav.acc.  =  9.810      Lunit/Tunit^2
       turn rad.  =  0.000      Lunit
       load fac.  =  1.000
    X  X_cg       = 0.4980      Lunit
    Y  Y_cg       =  0.000      Lunit
    Z  Z_cg       = -.1100      Lunit

   Enter parameter, value  (or  # - + N )   c> _
```

```
LOAD
cessna172
OPER
M
M 1111
V 35.0
G 9.81
D 1.225

d2 rm 0
d3 pm 0
d4 ym 0
c1
x 0.498

X
ST
cessna172_ST_1.out
O

quit
```

MATLAB Demo

- Download AVL_plotting.m and AVL_run.m
- AVL_run('cessna172',35:5:75,0.498)





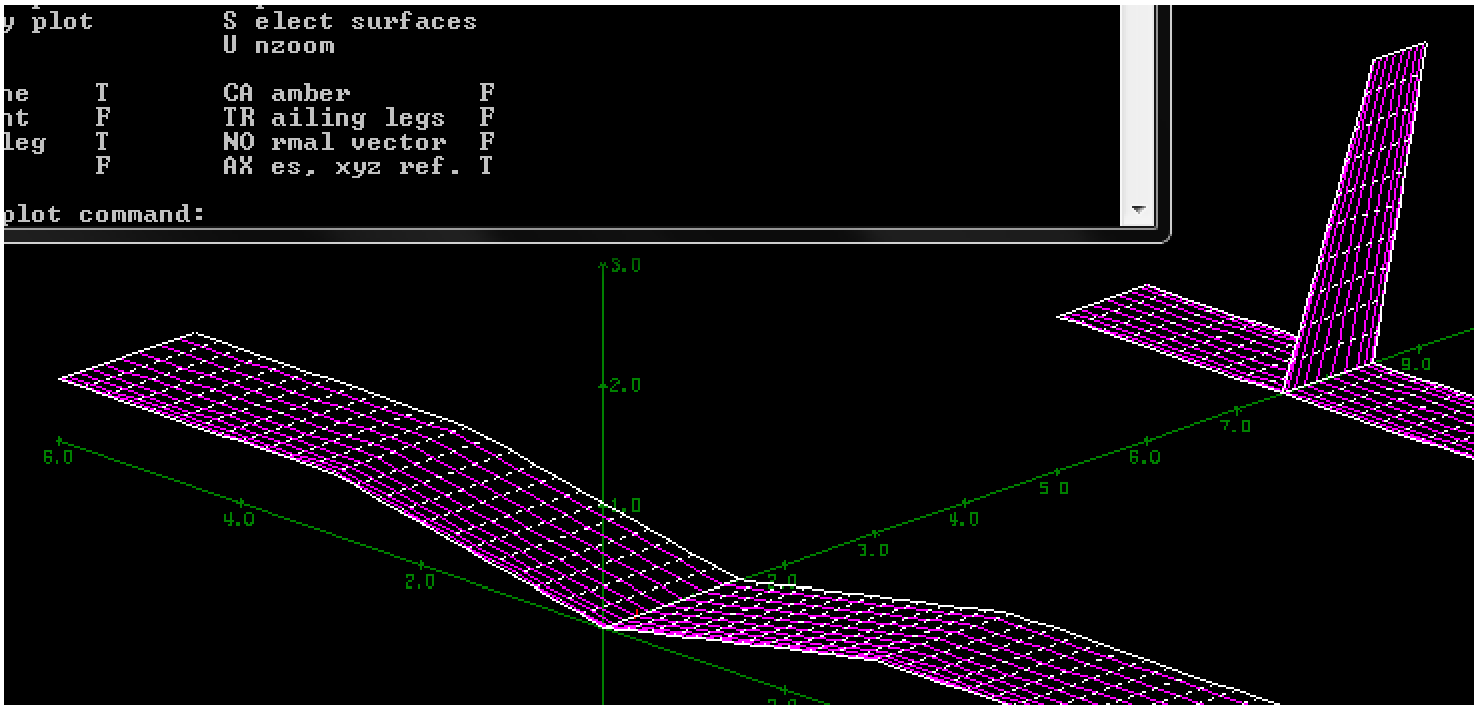
Questions?

Code Demo

- Download avl.exe
- Opening .avl file – use Notepad++ or Sublime Text 2
  - Drag and drop
  - Avl.exe, load command
- Edit the .avl file
  - Change a section
  - Change duplication
- Over-constrained
  - Do not define alpha and control deflections
- Visualize forces
  - Change flap deflection [d1]
  - Execute [x] and open geometry [g]
  - Show normal forces [no]
  - Enter keystroke mode [k], select figure and use [l] and [r] to navigate

Quiz

1. Using the figure, how many surfaces are defined, and how many sections are defined? Only consider half of the aircraft.



2. In the code header, what do Xref, Yref, and Zref represent for trimmed flight?