Computational Aircraft Prototype Syntheses

Training Session 5
Aero Modeling: AVL and masstran

ESP v1.18

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Overview

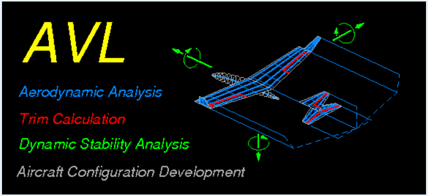
- AVL Overview
  - AVL Geometry Definition
  - Reference Quantities
- Control Surfaces and Stability Derivatives
- AVL Eigenmode Analysis
  - Pure AVL
  - AVL and masstran
- Suggested Exercises

Athena Vortex Lattice – AVL

- Aerodynamic and flight-dynamic analysis of rigid aircraft

Extended Vortex-Lattice Model

- Aerodynamic Components
  - Lifting surfaces
  - Slender bodies
- Control deflections
  - Via normal-vector tilting
  - Leading edge or trailing edge flaps
- General freestream description
  - alpha,beta flow angles
  - p,q,r aircraft rotation
- Aerodynamic outputs
  - forces and moments, in body or stability axes
  - Force and moment derivatives w.r.t. angles, rotations, controls



Athena Vortex Lattice – AVL cont.

Trim Calculation

- Operating variables
  - alpha,beta
  - p,q,r
  - control deflections
- Constraints
  - direct constraints on variables
  - indirect constraints via specified CL, moments
  - level or banked horizontal flight
  - steady pitch rate (looping) flight

Eigenmode analysis

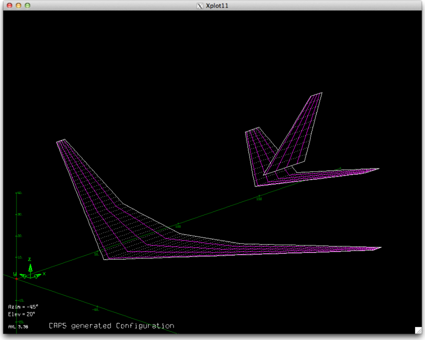
- Predicts flight stability characteristics
- Rigid-body, quasi-steady aero model
- Eigenvalue root progression with a parameter
- Display of eigenmode motion in real time

Vortex Lattice Geometry

Geometry specified with airfoil sections

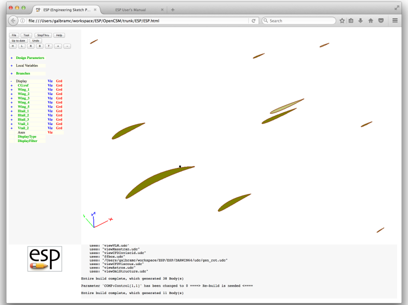
```
#--------------------------------------------------
SURFACE
WING
#Nchordwise   Cspace   Nspanwise   Sspace
1             1.0      16          -2.0
YDUPLICATE
0.0

SECTION
#Xle     Yle     Zle      Chord    Ainc   Nspanwise   Sspace
-0.25    0.      0.       1.000    0.     8           1.0
AIRFOIL
naca2412.dat

SECTION
#Xle     Yle     Zle      Chord    Ainc   Nspanwise   Sspace
-0.175   7.5     0.5      0.700    0.     0           0
AIRFOIL
naca0012.dat
```

VLM geometry with flat panels

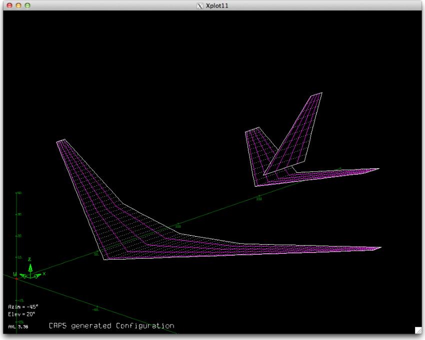


Vortex Lattice Geometry

ESP geometry airfoil sections

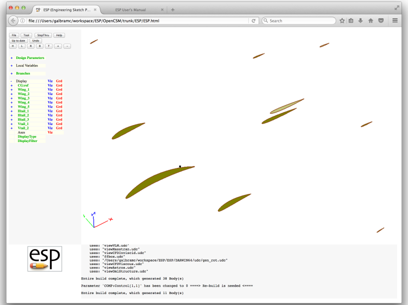


VLM geometry with flat panels



Vortex Lattice Geometry

ESP geometry airfoil sections



View Concept and VLM in ESP

---

cd training/CAPS/ESP
serveCSM transport.csm

VIEW:Concept	1
VIEW:VLM	1

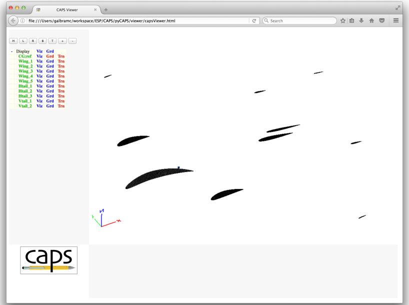
Checking the Geometry with pyCAPS

session05/avl_1_TransportGeom.py

```python
# Load geometry [.csm] file
filename = os.path.join("..","ESP","transport.csm")
print ("\n==> Loading geometry from file \""+filename+"\"...")
transport = myProblem.loadCAPS(filename)

# Change to VLM view
transport.setGeometryVal("VIEW:Concept", 0)
transport.setGeometryVal("VIEW:VLM"    , 1)

# view the geometry with the capsViewer
print ("\n==> Viewing transport bodies...")
transport.viewGeometry()

# Load AVL AIM
print ("\n==> Loading AVL aim...")
avl = myProblem.loadAIM(aim         = "avlAIM",
                        analysisDir = "workDir_avl_1_TransportGeom")

# view avl bodies with the capsViewer
print ("\n==> Viewing avl bodies...")
avl.viewGeometry()
```

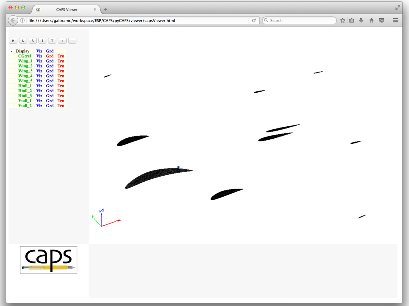
Checking the Geometry with pyCAPS

transport.viewGeometry()

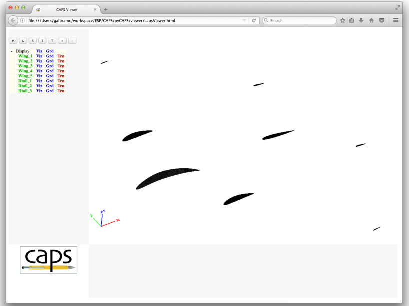


Checking the Geometry with pyCAPS

transport.viewGeometry()



avl.viewGeometry()



Checking the Geometry with pyCAPS

ESP/viewVLM.udc

```
    INTERSECT
        #ATTRIBUTE capsAIM          vlmAIMs
        ATTRIBUTE capsGroup         $Vtail
```

- Very rich input data set
  - Many geometric parameter
  - Multiple bodies
  - Many attributes on `BODY/FACE/EDGE/NODE`
- Not all error checking can be automated
- Significant user responsibility to check consistency
- Always check initial setup as much as possible

AVL AIM Documentation

Reference Quantities

AVL Input Header

```
!Sref      Cref     Bref
12.0       1.0      15.0
!Xref      Yref     Zref
0.0        0.0       0.0
```

ESP/viewVLM.udc

```
RESTORE   WingOml
INTERSECT
    ATTRIBUTE capsAIM            vlmAIMs
    ATTRIBUTE capsReferenceArea  wing:area
    ATTRIBUTE capsReferenceSpan  wing:span
    ATTRIBUTE capsReferenceChord wing:mac
    ATTRIBUTE capsReferenceX     wing:xroot+wing:mac/4
```

capsReference* attributes

Sref	capsReferenceArea	area for coefficients (C_L, C_D, C_m, etc)
Cref	capsReferenceChord	chord for pitching moment (C_m)
Bref	capsReferenceSpan	span for roll,yaw moments (C_l, C_n)
Xref	capsReferenceX	location for moments, rotation rates

capsReference* attributes on one or more bodies (consistent)

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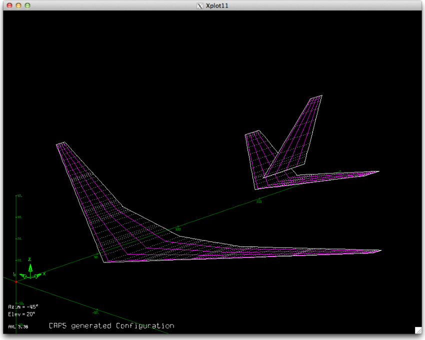
Vortex Lattice Geometry with Controls

- Controls specified with airfoil sections
- Airfoil interpolation?

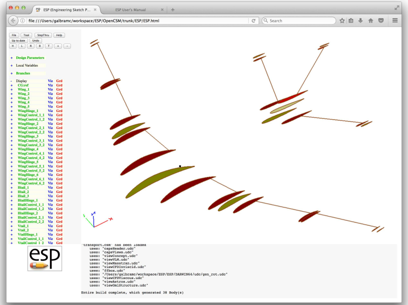
```
#-------------------------------------------------
SURFACE
STAB
#Nchordwise  Cspace  Nspanwise  Sspace
1            1.0     7          -2.0
YDUPLICATE
0.0

SECTION
#Xle     Yle     Zle      Chord    Ainc  Nspanwise  Sspace
6.0     0.      0.0      0.4      0.    7          -1.25
CONTROL
elevator  1.0  0.0  0. 0. 0.  1

SECTION
#Xle     Yle     Zle      Chord    Ainc  Nspanwise  Sspace
-0.075  2.00    0.0      0.3      0.    0          0
CONTROL
elevator  1.0  0.0  0. 0. 0.  1
```

Mesh clustering around controls

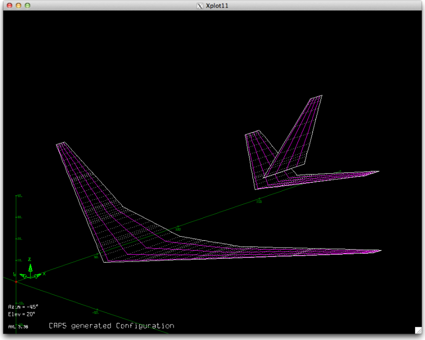


Vortex Lattice Geometry with Controls

ESP control airfoil sections

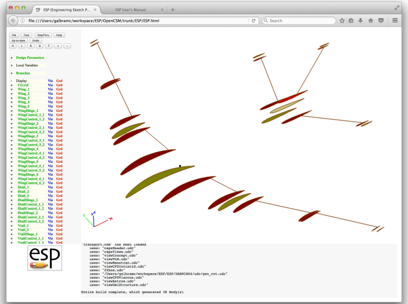


Mesh clustering around controls



Vortex Lattice Geometry with Controls

ESP control airfoil sections



View Concept and VLM in ESP

---

cd training/CAPS/ESP
serveCSM transport.csm

VIEW:Concept	1
VIEW:VLM	1
COMP:Control	1

vlmControl_“Name” Attribute

- vlmControl_“Name” specifies a section with a control surface
  - “Name” is the name of the control surface
  - Value is chord fraction of hinge line

session05/avlPlaneVanilla.csm

```
UDPRIM    naca  Thickness wing:thick  Camber wing:camber
SCALE     wing:croot
ROTATEX   90        0         0
TRANSLATE wing:xroot    0    wing:zroot
    ATTRIBUTE capsGroup              $Wing
    ATTRIBUTE vlmControl_AileronLeft  0.8  #Hinge line 80% chord
    ATTRIBUTE vlmControl_AileronRight 0.8  #Hinge line 80% chord
```

session05/avl_2_PlaneVanillaControl.py

```
# Set control surface parameters
aileronLeft  = {"deflectionAngle" : -25.0}
aileronRight = {"deflectionAngle" :  25.0}
elevator     = {"deflectionAngle" :  5.0}
rudder       = {"deflectionAngle" : -2.0}

avl.setAnalysisVal("AVL_Control", [("AileronLeft" , aileronLeft ),
                                   ("AileronRight", aileronRight),
                                   ("Elevator"    , elevator    ),
                                   ("Rudder"      , rudder      )])
```

ESP/transport.csm

```
# wing hinge lines
DIMENSION wing:hinge         6 9 1 # ymin                      ymax
#                            theta   x/c   y/span   z/t       x/c   y/span z/t     gap   grp
DESPMTR   wing:hinge        "-10.0;  0.75; -0.98;  0.50;    0.75; -0.70; 0.50;  0.25; 1;  \ left aileron
                             +10.0;  0.75; -0.69;  0.00;    0.75; -0.43; 0.00;  0.25; 2;  \ left oflap
                             +15.0;  0.85; -0.33;  0.00;    0.90; -0.14; 0.00;  0.25; 3;  \ left iflap
                             +15.0;  0.90;  0.14;  0.00;    0.85;  0.33; 0.00;  0.25; 3;  \ rite iflap
                             +10.0;  0.75;  0.43;  0.00;    0.75;  0.69; 0.00;  0.25; 2;  \ rite oflap
                             +10.0;  0.75;  0.70;  0.50;    0.75;  0.98; 0.50;  0.25; 4"  # rite aileron
```

ESP/viewVLM.udc

```
                    ATTRIBUTE capsGroup                             $Wing
                    ATTRIBUTE capsDiscipline                        $Aerodynamic
                    ATTRIBUTE _name                                !$WingControl_+ihinge+$_1
                    ATTRIBUTE !$vlmControl_WingControl+tagIndex xoverc1
```

session05/avl_3_TransportControl.py

```
# Set up control surface deflections based on the information in the csm file
controls = []

hinge = transport.getGeometryVal("wing:hinge")
for i in range(len(hinge)):
    controls.append(("WingControl_"+str(int(hinge[i][8])), {"deflectionAngle": hinge[i][0]}))
```

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Eigenmode Analysis

Eigenmode analysis

- Requires realistic:
  - Configuration
  - Mass, CG, and inertia data
  - Flight conditions

- All in with dimensional units
  - Units of body defined by `capsLength` attribute

ESP/transport.csm

```
# Define length units of the geometry
ATTRIBUTE capsLength       $ft
```

- Stable configuration: all negative real Eigen values

- Specifying Eigenmode Analysis dimensional inputs

session05/avl_4_TransportEigen.py

```
I = "massInertia"
# Inspired by the b737.mass avl example file
#                      mass                CGx  CGy CGz             Ixx     Iyy      Izz
cockpit   = {"mass":[ 3000, "lb"], "CG":[[  8,  0,  5], "ft"], I:[[0.    ,  0.    ,  0.   ], "lb*ft^2"]}
wing      = {"mass":[19420, "lb"], "CG":[[ 78,  0, -1], "ft"], I:[[8.0e6,  0.1e6,  8.1e6], "lb*ft^2"]}
fuselage  = {"mass":[33720, "lb"], "CG":[[105,  0,  2], "ft"], I:[[0.7e6, 18.9e6, 19.6e6], "lb*ft^2"]}
tailcone  = {"mass":[  310, "lb"], "CG":[[145,  0,  0], "ft"], I:[[0.    ,  0.    ,  0.   ], "lb*ft^2"]}
Htail     = {"mass":[  528, "lb"], "CG":[[160,  0,  2], "ft"], I:[[0.0e6,  0.0e6,  0.0e6], "lb*ft^2"]}
Vtail     = {"mass":[  616, "lb"], "CG":[[100,  0,  8], "ft"], I:[[0.1e6,  0.0e6,  0.1e6], "lb*ft^2"]}
Main_gear = {"mass":[ 4500, "lb"], "CG":[[ 76,  0, -4], "ft"], I:[[0.5e6,  0.0  ,  0.5e6], "lb*ft^2"]}
Nose_gear = {"mass":[ 1250, "lb"], "CG":[[ 36,  0, -5], "ft"], I:[[0.    ,  0.    ,  0.   ], "lb*ft^2"]}

avl.setAnalysisVal("MassProp", [("cockpit"  , cockpit  ),
                                ("wing"     , wing     ),
                                ("fuselage" , fuselage ),
                                ("tailcone" , tailcone ),
                                ("Htail"    , Htail    ),
                                ("Vtail"    , Vtail    ),
                                ("Main_gear", Main_gear),
                                ("Nose_gear", Nose_gear)])
avl.setAnalysisVal("Gravity" , 32.18   , units="ft/s^2"   )
avl.setAnalysisVal("Density" , 0.002378, units="slug/ft^3")
avl.setAnalysisVal("Velocity", 250.0   , units="m/s"      )
```

Eigenmode Analysis with masstran

- Check bodies passed to avl and masstran

session05/avl_masstran_5_Geom.py

```
# Change to VLM view and OmlStructure
transport.setGeometryVal("VIEW:Concept",      0)
transport.setGeometryVal("VIEW:VLM",          1)
transport.setGeometryVal("VIEW:OmlStructure", 1)

# Enable fuselage and lifting surfaces
transport.setGeometryVal("COMP:Wing"    , 1)
transport.setGeometryVal("COMP:Fuse"    , 1)
transport.setGeometryVal("COMP:Htail"   , 1)
transport.setGeometryVal("COMP:Vtail"   , 1)
transport.setGeometryVal("COMP:Control", 0)

avl = myProblem.loadAIM(aim = "avlAIM",
                        analysisDir = "workDir_avl_5_Geom")

print ("AVL geometry")
avl.viewGeometry()

masstran = myProblem.loadAIM(aim = "masstranAIM",
                             analysisDir = "workDir_masstran_5_Geom")

print ("Masstran geometry")
masstran.viewGeometry()
```

Eigenmode Analysis with masstran

- Get mass properties from masstran

session05/avl_masstran_6_Eigen.py

```
# Set materials
unobtainium  = { "density" : 200 } # lb/ft^3
masstran.setAnalysisVal("Material", ("Unobtainium", unobtainium))

# Set property
shell  = {"propertyType"      : "Shell",
          "material"          : "Unobtainium",
          "membraneThickness" : 0.02} # ft

masstran.setAnalysisVal("Property", [("fuseSkin", shell),
                                     ("wingSkin", shell),
                                     ("htailSkin", shell),
                                     ("vtailSkin", shell)])

print ("\n==> Computing mass properties...")
masstran.preAnalysis()
masstran.postAnalysis()

aircraft_mass = masstran.getAnalysisOutVal("Mass")
aircraft_CG   = masstran.getAnalysisOutVal("CG")
aircraft_I    = masstran.getAnalysisOutVal("I_Vector")

aircraft_skin = {"mass":[aircraft_mass,"lb"],"CG":[aircraft_CG,"ft"],"massInertia":[aircraft_I,"lb*ft^2"]}
```

Eigenmode Analysis with masstran

- Pass mass properties to AVL

session05/avl_masstran_6_Eigen.py

```
# Taken from the b737.mass avl example file
I = "massInertia"
#                    mass                 CGx  CGy  CGz            Ixx    Iyy  Izz
cockpit   = {"mass":[3000, "lb"], "CG":[[  8,  0.,  5], "ft"], I:[[0.0  , 0.0, 0.0  ], "lb*ft^2"]}
Main_gear = {"mass":[4500, "lb"], "CG":[[ 86,  0., -4], "ft"], I:[[0.5e6, 0.0, 0.5e6], "lb*ft^2"]}
Nose_gear = {"mass":[1250, "lb"], "CG":[[ 26,  0., -5], "ft"], I:[[0.0  , 0.0, 0.0  ], "lb*ft^2"]}

avl.setAnalysisVal("MassProp", [("aircraft_skin", aircraft_skin),
                                ("cockpit"      , cockpit      ),
                                ("Main_gear"    , Main_gear    ),
                                ("Nose_gear"    , Nose_gear    )])
avl.setAnalysisVal("Gravity" , 32.18   , units="ft/s^2")
avl.setAnalysisVal("Density" , 0.002378, units="slug/ft^3")
avl.setAnalysisVal("Velocity", 250.0   , units="m/s")
```

Suggested Exercises

Multiple Shells

- Create multiple materials and shell properties for the transport components in avl_masstran_6_Eigen.py

Multiple AIMs

- Create multiple masstran AIM instances for the transport components in avl_masstran_6_Eigen.py
  - Note: viewOmlStructure has same `capsIntent` as F-118

Main Gear

- Use wing:xroot and wing:mac to position the main gear CGx in avl_masstran_6_Eigen.py as a fraction of wing:mac downstream of wing:xroot

Suggested Exercises Cont.

Stable Transport

- Resize tail and modify mass properties of avl_masstran_6_Eigen.py to make a stable transport (all negative real Eigen values)
  - See session05/transport_Htail.py as an example of sweeping through tail size

- Create your own (optionally share it `galbramc@mit.edu`)