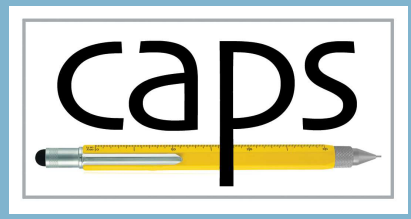
Computational Aircraft Prototype Syntheses



Training Session 5.2
Structures Analysis: ASTROS/NASTRAN

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Overview

- Modal analysis using ASTROS
  - Cantilever
  - Support node
- Static analysis using ASTROS
  - Cantilever
  - Orthotropic materials and coordinate systems
- Flutter analysis with NASTRAN

ASTROS Overview

Automated Structural Optimization System

- ZONA Technology, Inc.
  - Originally developed by Northrop Corporation under contract with AF Wright Aeronautical Laboratories
- Structural Modal and Static Analysis
- Aerodynamic Loads (Vortex Lattice Method)
- Aeroelastic Stability and Trim
- Control System Interaction
- Structural Sizing Optmization
- Sensitivity Analysis

micro-ASTROS (mASTROS)

- Limited mesh sizes
- No aerodynamic analysis

NASTRAN Overview

NASA STRucture ANalysis

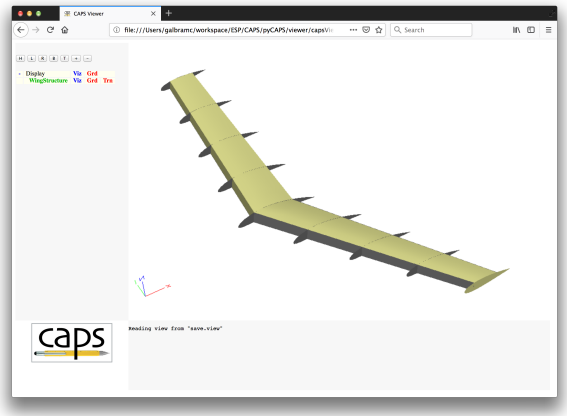
- MSC Software Corporation (MSC Nastran)
  - Originally developed for NASA in late 1960s by MSC
  - AutoDesk NEi Software (NEi Nastran)
  - Siemens PLM Software (NX Nastran)
  - Open source (https://github.com/nasa/NASTRAN-95)
- Structural Modal and Static Analysis
- Aerodynamic Loads (Vortex Lattice Method)
- Aeroelastic Stability and Trim
- Structural Assembly Modeling
- Automated Structural Optimization

ASTROS AIM Inputs and Outputs

ASTROS AIM Documentation

wing3.csm Geometry

- Box structure with spars and ribs
- Cantilever root constraint
- Support node at root



ESP/wing3.csm

```
DESPMTR   VIEW:ClampedStructure 0
DESPMTR   VIEW:SupportStructure 0
DESPMTR   VIEW:BoxStructure     0
```

Structures Meshing

- Use egadsTessAIM for quad surface tesseallation
- Coarsest possible grid for expedience
- Consistent for all examples in this session

session5.2/astros_1_ModalClamped.py

```
# Load EGADS tess aim
tess = myProblem.loadAIM(aim = "egadsTessAIM",
                         analysisDir = "workDir_Tess")

# Set EGADS body tessellation parameters to generate minmal meshing
tess.setAnalysisVal("Tess_Params", [0, 1, 30])

# Use regularized quads
tess.setAnalysisVal("Mesh_Elements", "Quad")

# Run AIM pre/post-analysis to generate the surface mesh
print ("\n==> Generating Mesh...")
tess.preAnalysis()
tess.postAnalysis()
```

ASTROS Cantilever Modal Analysis: Setup

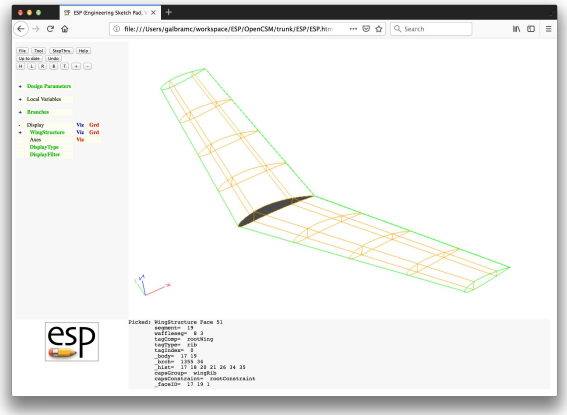
- Cantilever constraint on wing root rib `FACE/EDGE/NODE` using `capsConstraint`

ESP/viewStructure.udc

```
        # Constrainted applied to FACE/EDGE/NODE of root rib
        UDPRIM    editAttr  filename  <<
            FACE HAS      tagComp=rootWing
            SET           capsConstraint=rootConstraint

            EDGE ADJ2FACE tagComp=rootWing
            SET  capsConstraint=rootConstraint

            NODE ADJ2FACE tagComp=rootWing
            SET  capsConstraint=rootConstraint
>>
```



session5.2/astros_1_ModalClamped.py

```
wing.setGeometryVal("VIEW:Concept"          , 0)
wing.setGeometryVal("VIEW:ClampedStructure", 1)
wing.setGeometryVal("VIEW:BoxStructure"     , 1)
```

```
# Set constraints
constraint = {"groupName"     : ["rootConstraint"],
              "dofConstraint" : 123456}
astros.setAnalysisVal("Constraint", ("rootConstraint", constraint))
```

ASTROS Cantilever Modal Analysis: Setup

- Specify the type of analysis
- Build material database

session5.2/astros_1_ModalClamped.py

```
# Set analysis type
eigen = { "analysisType"          : "Modal",
          "extractionMethod"      : "SINV",
          "frequencyRange"        : [0, 10],
          "numEstEigenvalue"      : 1,
          "numDesiredEigenvalue" : 10,
          "eigenNormaliztion"     : "MASS"}
astros.setAnalysisVal("Analysis", ("EigenAnalysis", eigen))

# Set materials
unobtainium  = {"youngModulus" : 2.2E6 ,
                "poissonRatio" : .5,
                "density"      : 7850}
madeupium    = {"materialType" : "isotropic",
                "youngModulus" : 1.2E5 ,
                "poissonRatio" : .5,
                "density"      : 7850}
astros.setAnalysisVal("Material", [("Unobtainium", unobtainium),
                                   ("Madeupium", madeupium)])
```

ASTROS Cantilever Modal Analysis: Setup

- Define shell properties that will be associated with `capsGroup`
- Properties connected to materials via their name

session5.2/astros_1_ModalClamped.py

```
# Set properties
skinShell  = {"propertyType"         : "Shell",
              "material"             : "unobtainium",
              "bendingInertiaRatio"  : 1.0,
              "shearMembraneRatio"   : 0, # Turn of shear - no materialShear
              "membraneThickness"    : 0.05}
ribShell   = {"propertyType"         : "Shell",
              "material"             : "unobtainium",
              "bendingInertiaRatio"  : 1.0,
              "shearMembraneRatio"   : 0, # Turn of shear - no materialShear
              "membraneThickness"    : 0.1}
sparShell  = {"propertyType"         : "Shell",
              "material"             : "madeupium",
              "bendingInertiaRatio"  : 1.0,
              "shearMembraneRatio"   : 0, # Turn of shear - no materialShear
              "membraneThickness"    : 0.2}
```

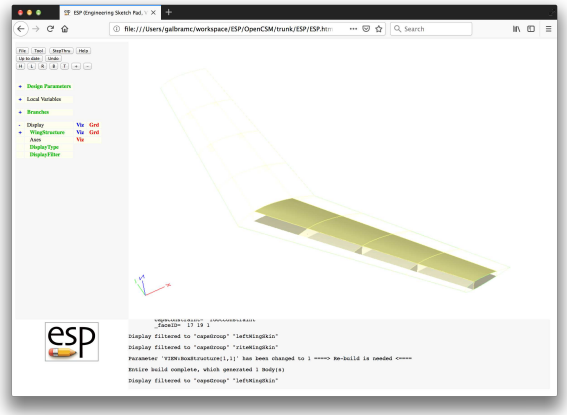
ASTROS Cantilever Modal Analysis: Setup

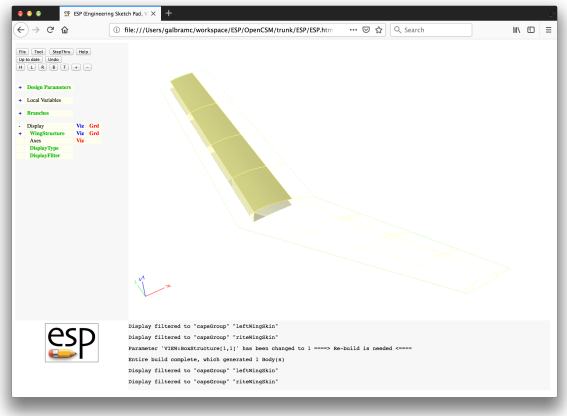
- Associate shell properties with `capsGroup`

ESP/viewStructure.udc

```
# Identify the capsGroups for FEA properties
UDPRIM    editAttr  filename  <<
    FACE HAS         tagComp=leftWing
    ANDNOT ADJ2EDGE  tagType=leadingEdge
    ANDNOT ADJ2EDGE  tagType=trailingEdge
    ANDNOT ADJ2FACE  tagType=trailingEdge
    SET              capsGroup=leftWingSkin

    FACE HAS         tagComp=riteWing
    ANDNOT ADJ2EDGE  tagType=leadingEdge
    ANDNOT ADJ2EDGE  tagType=trailingEdge
    ANDNOT ADJ2FACE  tagType=trailingEdge
    SET              capsGroup=riteWingSkin
```





session5.2/astros_1_ModalClamped.py

```
astros.setAnalysisVal("Property", [("leftWingSkin", skinShell),
                                   ("riteWingSkin", skinShell),
                                   ("wingRib"     ,  ribShell),
                                   ("wingSpar1"   , sparShell),
                                   ("wingSpar2"   , sparShell)])
```

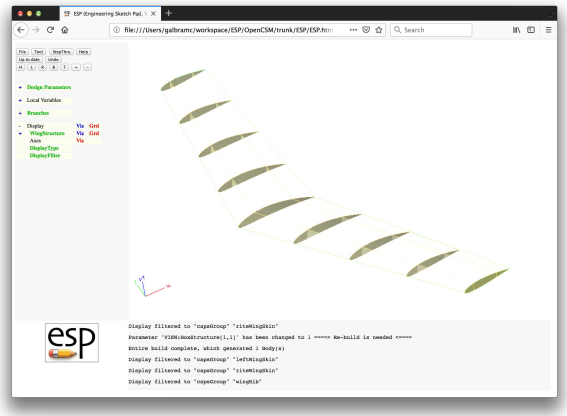
ASTROS Cantilever Modal Analysis: Setup

- Associate shell properties with `capsGroup`

ESP/viewStructure.udc

```
FACE HAS        tagType=rib
SET             capsGroup=wingRib

FACE HAS        tagType=tip
SET             capsGroup=wingRib
```



session5.2/astros_1_ModalClamped.py

```
astros.setAnalysisVal("Property", [("leftWingSkin", skinShell),
                                   ("riteWingSkin", skinShell),
                                   ("wingRib"     ,  ribShell),
                                   ("wingSpar1"   , sparShell),
                                   ("wingSpar2"   , sparShell)])
```

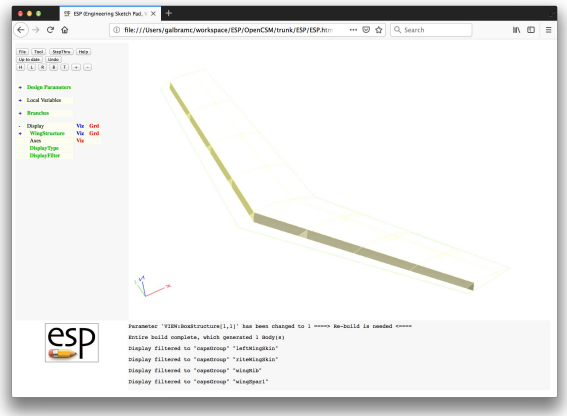
ASTROS Cantilever Modal Analysis: Setup

- Associate shell properties with `capsGroup`

ESP/viewStructure.udc

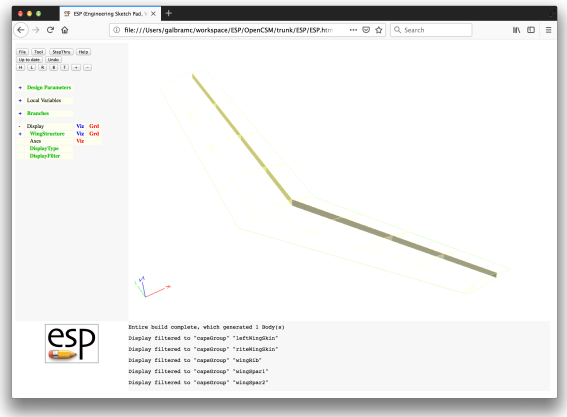
```
FACE HAS        tagType=spar tagIndex=1
SET             capsGroup=wingSpar1

FACE HAS        tagType=spar tagIndex=2
SET             capsGroup=wingSpar2
```



session5.2/astros_1_ModalClamped.py

```
astros.setAnalysisVal("Property", [("leftWingSkin", skinShell),
                                   ("riteWingSkin", skinShell),
                                   ("wingRib"     ,  ribShell),
                                   ("wingSpar1"   , sparShell),
                                   ("wingSpar2"   , sparShell)])
```



ASTROS Cantilever Modal Analysis: Execution

- ASTROS requires “ASTRO.D01” and “ASTRO.IDX” in run directory

session5.2/astros_1_ModalClamped.py

```
astrosInstallDir = os.environ['ESP_ROOT'] + os.sep + "bin" + os.sep

# Copy files needed to run astros
files = ["ASTRO.D01", "ASTRO.IDX"]
for file in files:
    try:
        shutil.copy2(astrosInstallDir + file, file)
    except:
        print ('Unable to copy "' + file + '"')
        raise

# Run micro-ASTROS via system call
os.system("mastros.exe < " + Proj_Name +  ".dat > " + Proj_Name + ".out")

# Remove temporary files
for file in files:
    if os.path.isfile(file):
        os.remove(file)
```

ASTROS Cantilever Modal Analysis: Output

- Print the Eigen frequencies

session5.2/astros_1_ModalClamped.py

```
# Get list of Eigen-frequencies
freqs = astros.getAnalysisOutVal("EigenFrequency")

print ("\n--> Eigen-frequencies:")
for i in range(len(freqs)):
    print ("    " + repr(i+1).ljust(2) + ": " + str(freqs[i]))
```

ASTROS Support Modal Analysis: Setup

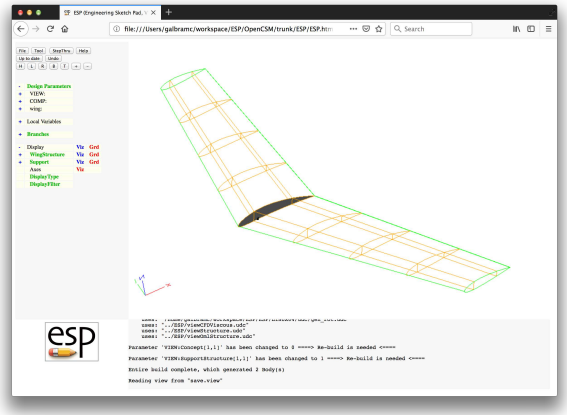
- Support connection on wing root rib `FACE/EDGE/NODE` using `capsConnectLink` and `capsConnect`

ESP/viewStructure.udc

```
# Connections to support on FACE/EDGE/NODE of root rib
UDPRIM    editAttr  filename  <<
    FACE HAS      tagComp=rootWing
    SET           capsConnectLink=ribRoot

    EDGE ADJ2FACE tagComp=rootWing
    SET  capsConnectLink=ribRoot

    NODE ADJ2FACE tagComp=rootWing
    SET  capsConnectLink=ribRoot
```



```
# Point Connecting to ribRoot to apply boundary conditions
POINT  wing:xroot+wing:chordr/4 wing:yroot wing:zroot
    ATTRIBUTE capsConnect       $ribRoot
    ATTRIBUTE capsGroup         $ribSupport
    ATTRIBUTE capsConstraint    $ribRootPoint
```

session5.2/astros_2_ModalSupport.py

```
wing.setGeometryVal("VIEW:Concept"          , 0)
wing.setGeometryVal("VIEW:SupportStructure", 1)
wing.setGeometryVal("VIEW:BoxStructure"     , 1)
```

ASTROS Support Modal Analysis: Setup

- Define connection and support types
- Define constraint on the support node

ESP/viewStructure.udc

```
    # Point Connecting to ribRoot to apply boundary conditions
    POINT  wing:xroot+wing:chordr/4 wing:yroot wing:zroot
        ATTRIBUTE capsConnect       $ribRoot
        ATTRIBUTE capsGroup         $ribSupport
        ATTRIBUTE capsConstraint    $ribRootPoint
```

session5.2/astros_2_ModalSupport.py

```
# Defined Connections
connection = {"dofDependent"   : 123456,
              "connectionType" : "RigidBody"}
astros.setAnalysisVal("Connect",("ribRoot", connection))

# Set supports
support = {"groupName" : ["ribRootPoint"],
           "dofSupport": 3}
astros.setAnalysisVal("Support", ("ribSupport", support))

# Set constraints
constraint = {"groupName"     : ["ribRootPoint"],
              "dofConstraint" : 12456}
astros.setAnalysisVal("Constraint", ("ribConstraint", constraint))
```

ASTROS Support Modal Analysis: Setup

- Define concentrated mass with moments of inertia on support node

ESP/viewStructure.udc

```
# Point Connecting to ribRoot to apply boundary conditions
POINT  wing:xroot+wing:chordr/4 wing:yroot wing:zroot
    ATTRIBUTE capsConnect       $ribRoot
    ATTRIBUTE capsGroup         $ribSupport
    ATTRIBUTE capsConstraint    $ribRootPoint
```

session5.2/astros_2_ModalSupport.py

```
mass    =   {"propertyType" : "ConcentratedMass",
             "mass"         : 1.0E5,
                              #I11  I12  I22    I31  I32  I33
             "massInertia"  : [0.0, 0.0, 1.0E5, 0.0, 0.0, 0.0]}

astros.setAnalysisVal("Property", [("leftWingSkin", skinShell),
                                   ("riteWingSkin", skinShell),
                                   ("wingRib"     ,  ribShell),
                                   ("wingSpar1"   , sparShell),
                                   ("wingSpar2"   , sparShell),
                                   ("ribSupport"  , mass     )])
```

Overview

- Modal analysis using ASTROS
  - Cantilever
  - Support node
- Static analysis using ASTROS
  - Cantilever
  - Orthotropic materials and coordinate systems
- Flutter analysis with NASTRAN

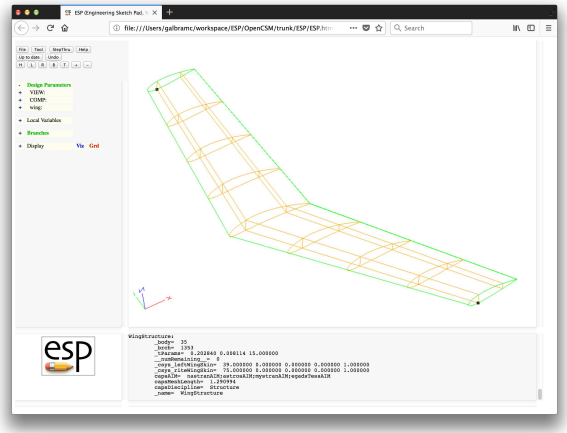
ASTROS Cantilever Static Analysis: Setup

- Static loads can be applied to entities marked with `capsLoad`
- `capsLoad` on NODE → point load
- `capsLoad` on EDGE → multi-point load (future linear load)
- `capsLoad` on FACE → pressure load

ESP/viewStructure.udc

```
# Define the point(s) at which point loads can be applied
UDPRIM    editAttr  filename  <<
    NODE ADJ2FACE tagComp=leftWing tagType=tip
    AND  ADJ2FACE tagType=lower
    AND  ADJ2FACE tagType=spar tagIndex=1
    SET           capsLoad=leftPointLoad

    NODE ADJ2FACE tagComp=riteWing tagType=tip
    AND  ADJ2FACE tagType=lower
    AND  ADJ2FACE tagType=spar tagIndex=1
    SET           capsLoad=ritePointLoad
```



session5.2/astros_3_StaticClamped.py

```
wing.setGeometryVal("VIEW:Concept"          , 0)
wing.setGeometryVal("VIEW:ClampedStructure", 1)
wing.setGeometryVal("VIEW:BoxStructure"     , 1)
```

ASTROS Cantilever Static Analysis: Setup

- Define loads to apply, and set analysis to static

ESP/viewStructure.udc

```
# Define the point(s) at which point loads can be applied
UDPRIM    editAttr  filename  <<
    NODE ADJ2FACE tagComp=leftWing tagType=tip
    AND  ADJ2FACE tagType=lower
    AND  ADJ2FACE tagType=spar tagIndex=1
    SET           capsLoad=leftPointLoad

    NODE ADJ2FACE tagComp=riteWing tagType=tip
    AND  ADJ2FACE tagType=lower
    AND  ADJ2FACE tagType=spar tagIndex=1
    SET           capsLoad=ritePointLoad
```

session5.2/astros_3_StaticClamped.py

```
# Define loads
leftLoad = {"loadType"          : "GridForce",
            "forceScaleFactor" : 1.e6,
            "directionVector"   : [0.0, 0.0, 1.0]}
riteLoad = {"loadType"          : "GridForce",
            "forceScaleFactor" : 2.e6,
            "directionVector"   : [0.0, 0.0, 1.0]}
astros.setAnalysisVal("Load", [("leftPointLoad", leftLoad ),
                               ("ritePointLoad", riteLoad )])

# Set analysis type
astros.setAnalysisVal("Analysis_Type", "Static")
```

ASTROS Cantilever Static Analysis: Output

- Print the displacements

session5.2/astros_3_StaticClamped.py

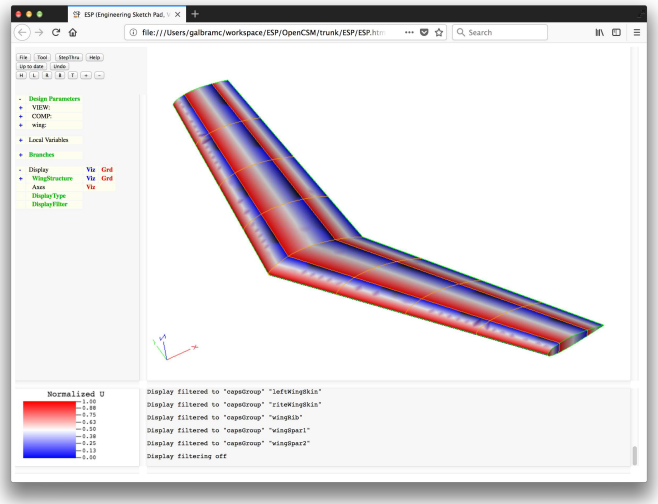
```
print ("\n--> Maximum displacements:")
print ("--> Tmax" , astros.getAnalysisOutVal("Tmax" ))
print ("--> T1max", astros.getAnalysisOutVal("T1max"))
print ("--> T2max", astros.getAnalysisOutVal("T2max"))
print ("--> T3max", astros.getAnalysisOutVal("T3max"))
```

Composite Materials: Coordinate system

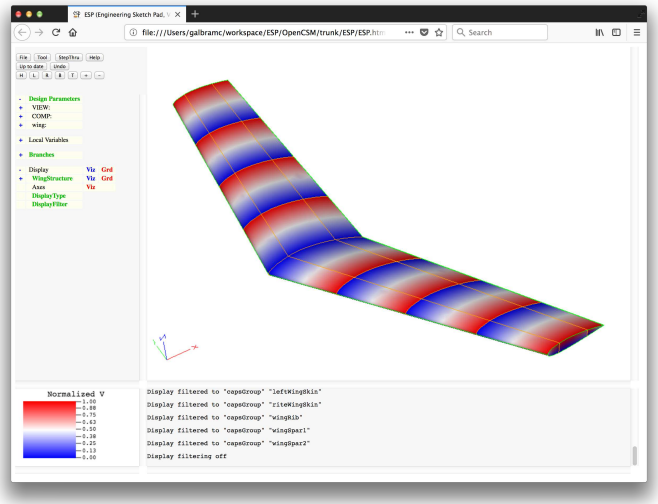
- Coordinate system `name` matches `capsGroup`

ESP/viewStructure.udc

```
# Apply the Csystems
# Name matches capsGroup that uses the Csystem
RESTORE   WingStruct          #iface;ubar0;vbar0;du2;dv2
    CSYSTEM   leftWingSkin   leftWingSkinCsys;0;0;0;1
    CSYSTEM   riteWingSkin   riteWingSkinCsys;0;0;0;1
```



Normalized u-coordinates



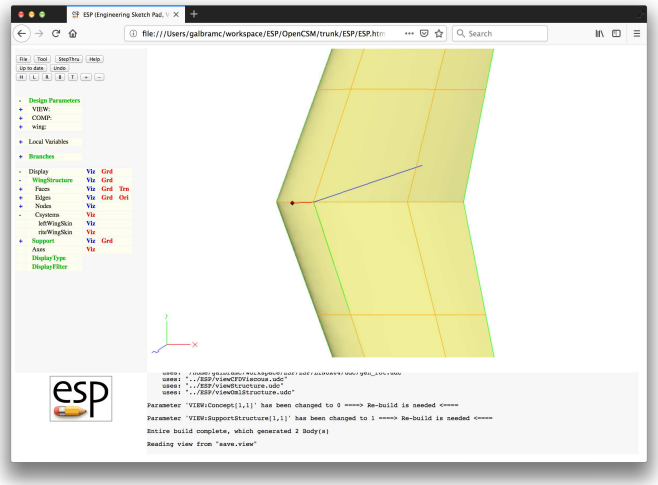
Normalized v-coordinates

Composite Materials: Coordinate system

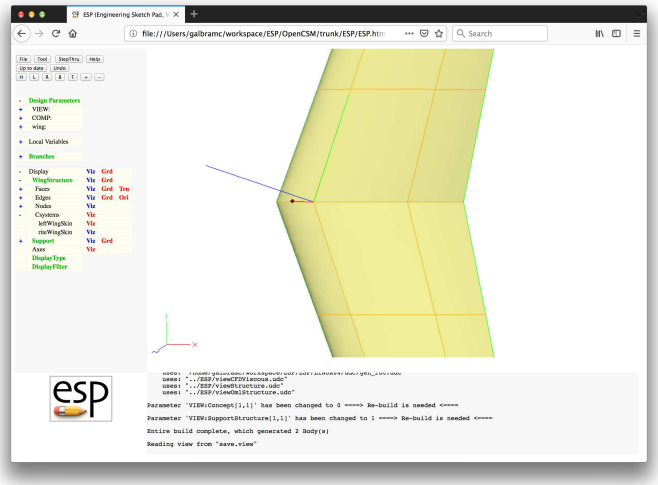
- Coordinate system `name` matches `capsGroup`

ESP/viewStructure.udc

```
# Apply the Csystems
# Name matches capsGroup that uses the Csystem
RESTORE   WingStruct          #iface;ubar0;vbar0;du2;dv2
    CSYSTEM   leftWingSkin   leftWingSkinCsys;0;0;0;1
    CSYSTEM   riteWingSkin   riteWingSkinCsys;0;0;0;1
```



leftWingSkin coordinate system



riteWingSkin coordinate system

Composite Materials: Define Material

- Define isotropic and orthotropic materials

session5.2/astros_4_Composite.py

```
# Set materials
Aluminum  = {"youngModulus" : 10.5E6 ,
             "poissonRatio" : 0.3,
             "density"      : 0.1/386,
             "shearModulus" : 4.04E6}
Graphite_epoxy = {"materialType"        : "Orthotropic",
                  "youngModulus"        : 20.8E6 ,
                  "youngModulusLateral" : 1.54E6,
                  "poissonRatio"        : 0.327,
                  "shearModulus"        : 0.80E6,
                  "density"             : 0.059/386,
                  "tensionAllow"        : 11.2e-3,
                  "tensionAllowLateral" : 4.7e-3,
                  "compressAllow"       : 11.2e-3,
                  "compressAllowLateral": 4.7e-3,
                  "shearAllow"          : 19.0e-3,
                  "allowType"           : 1}
astros.setAnalysisVal("Material", [("Aluminum", Aluminum),
                                   ("Graphite_epoxy", Graphite_epoxy)])
```

Composite Materials: Property

- `CompositeOrientation` angles relative to `CSYSTEM`

session5.2/astros_4_Composite.py

```
# Set properties
skinShell  = {"propertyType"           : "Composite",
              "shearBondAllowable"     : 1.0e6,
              "bendingInertiaRatio"    : 1.0,
              "shearMembraneRatio"     : 0, # Turn off shear - no materialShear
              "compositeMaterial"      : ["Graphite_epoxy"]*8,
              "compositeThickness"     : [0.00525]*8,
              "compositeOrientation"   : [0, 0, 0, 0, -45, 45, -45, 45],
              "symmetricLaminate"      : True,
              "compositeFailureTheory" : "STRAIN" }
ribShell   = {"propertyType"         : "Shell",
              "material"             : "Aluminum",
              "bendingInertiaRatio"  : 1.0,
              "shearMembraneRatio"   : 0, # Turn of shear - no materialShear
              "membraneThickness"    : 0.125 }
sparShell  = {"propertyType"          : "Shell",
              "material"             : "Aluminum",
              "bendingInertiaRatio"  : 1.0,
              "shearMembraneRatio"   : 0, # Turn of shear - no materialShear
              "membraneThickness"    : 0.125 }
astros.setAnalysisVal("Property", [("leftWingSkin", skinShell),
                                   ("riteWingSkin", skinShell),
                                   ("wingRib"     ,  ribShell),
                                   ("wingSpar1"   , sparShell),
                                   ("wingSpar2"   , sparShell)])
```

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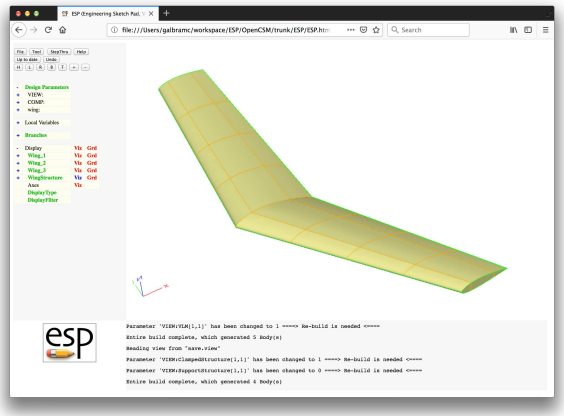
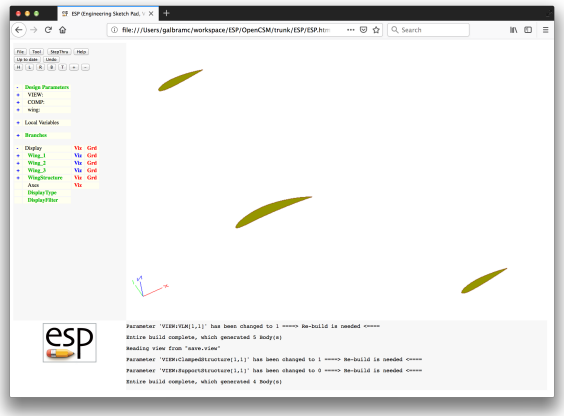
Flutter analysis with NASTRAN: Setup

- Cantilever aeroelastic flutter analysis



Structural body with full skin

```
ATTRIBUTE capsAIM $nastranAIM
ATTRIBUTE capsDiscipline $Structure
```



VLM Aero bodies

```
ATTRIBUTE capsAIM $nastranAIM
ATTRIBUTE capsDiscipline $Aerodynamic
```

session5.2/nastran_5_Flutter.py

```
# Change to Structures and VLM
wing.setGeometryVal("VIEW:Concept"          , 0)
wing.setGeometryVal("VIEW:VLM"              , 1)
wing.setGeometryVal("VIEW:ClampedStructure", 1)
```

Flutter analysis with NASTRAN: Setup

- Aeroelastic analysis coupled via `capsBound`

ESP/viewStructure.udc

```
# Set up for possible data transfer to other analyses
UDPRIM    editAttr  filename  <<
    FACE HAS      tagType=upper
    SET           capsBound=upperWing

    FACE HAS      tagType=lower
    SET           capsBound=lowerWing

    FACE HAS      tagType=tip tagIndex=1
    SET           capsBound=leftTip
```

session5.2/nastran_5_Flutter.py

```
# Set analysis type
nastran.setAnalysisVal("Analysis_Type", "AeroelasticFlutter")

# Aero with capsGroup for airfoil sections
wingVLM = {"groupName"         : "Wing",
           "numChord"          : 4,
           "numSpanPerSection" : 6}

# Note the surface name corresponds to the capsBound found in the *.csm file. This links
# the spline for the aerodynamic surface to the structural model
nastran.setAnalysisVal("VLM_Surface", ("upperWing", wingVLM))
```

Suggested Exercises

- Create your own