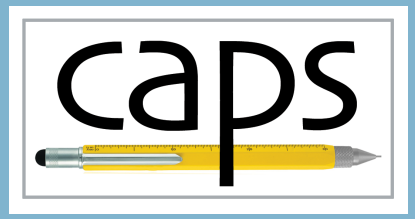
Computational Aircraft Prototype Syntheses



Training Session 10
Structures Analysis: ASTROS/NASTRAN

ESP v1.19

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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

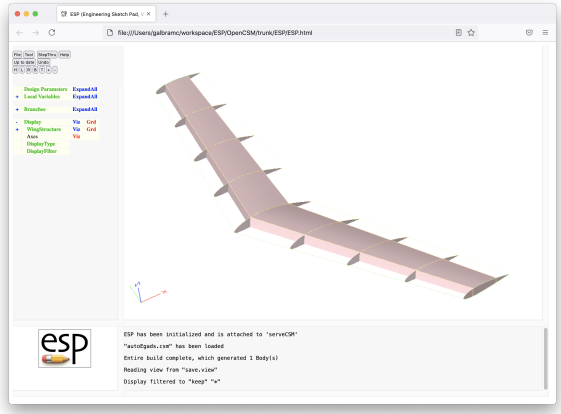
NASA STRucture ANalysis

- 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 Documentation

wing3.csm Geometry

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



ESP/wing3.csm

```
CFGPMTR   VIEW:ClampedStructure 0
CFGPMTR   VIEW:SupportStructure 0
CFGPMTR   VIEW:BoxStructure     0
```

Structures Meshing

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

session10/astros_1_ModalClamped.py

```
# Create EGADS tess aim
tess = myProblem.analysis.create(aim = "egadsTessAIM",
                                 name = "tess")

# No Tess vertexes on edges (minimial mesh)
tess.input.Edge_Point_Max = 2

# Use regularized quads
tess.input.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

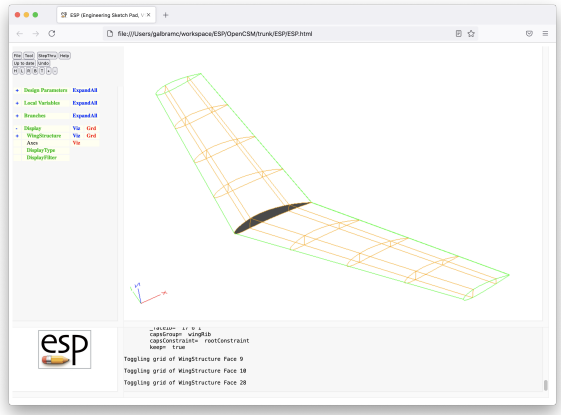
- Cantilever constraint on wing root rib `FACE/EDGE/NODE` using `capsConstraint`

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
>>
```



session10/astros_1_ModalClamped.py

```
# Set geometry variables to enable Box Structure with Clambed root
wing.cfgpmtr.VIEW.Concept          = 0
wing.cfgpmtr.VIEW.ClampedStructure = 1
wing.cfgpmtr.VIEW.BoxStructure     = 1
```

```
constraint = {"dofConstraint" : 123456}
astros.input.Constraint = {"rootConstraint": constraint}
```

ASTROS Cantilever Modal Analysis: Setup

- Specify the type of analysis
- Build material database

session10/astros_1_ModalClamped.py

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

# Set materials
unobtainium  = {"youngModulus" : 2.2E6 ,
                "poissonRatio" : .5,
                "density"      : 7850}
madeupium    = {"materialType" : "isotropic",
                "youngModulus" : 1.2E5 ,
                "poissonRatio" : .5,
                "density"      : 7850}
astros.input.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

session10/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}
```

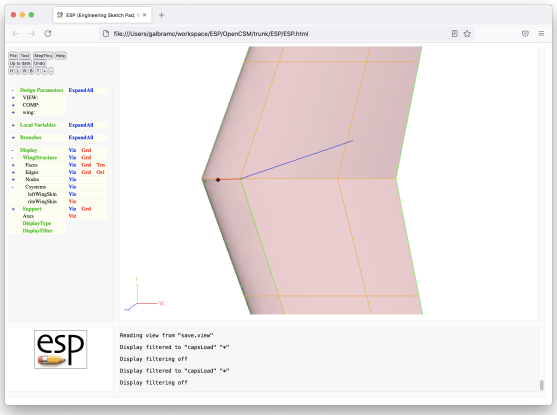
ASTROS Cantilever Modal Analysis: Setup

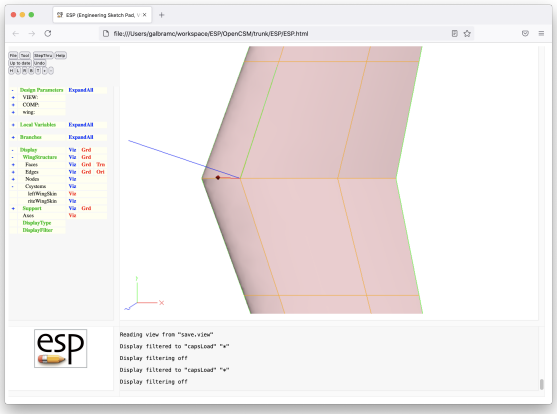
- Associate shell properties with `capsGroup`

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
```





session10/astros_1_ModalClamped.py

```
astros.input.Property = {"leftWingSkin": skinShell,
                         "riteWingSkin": skinShell,
                         "wingRib"     :  ribShell,
                         "wingSpar1"   : sparShell,
                         "wingSpar2"   : sparShell}
```

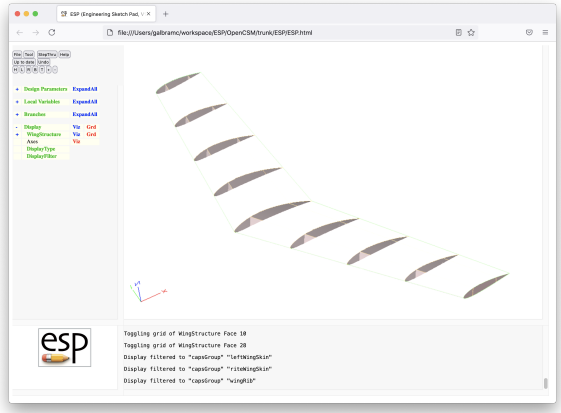
ASTROS Cantilever Modal Analysis: Setup

- Associate shell properties with `capsGroup`

ESP/viewStructure.udc

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

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



session10/astros_1_ModalClamped.py

```
astros.input.Property = {"leftWingSkin": skinShell,
                         "riteWingSkin": skinShell,
                         "wingRib"     :  ribShell,
                         "wingSpar1"   : sparShell,
                         "wingSpar2"   : sparShell}
```

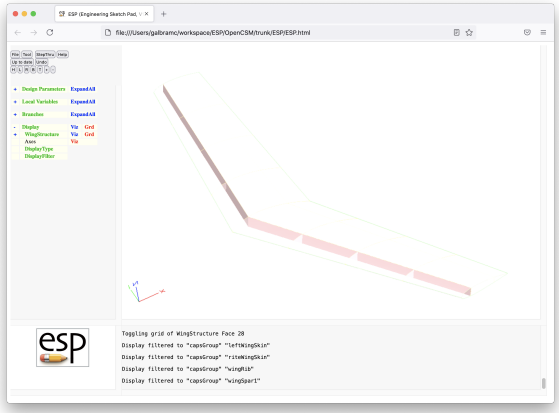
ASTROS Cantilever Modal Analysis: Setup

- Associate shell properties with `capsGroup`

ESP/viewStructure.udc

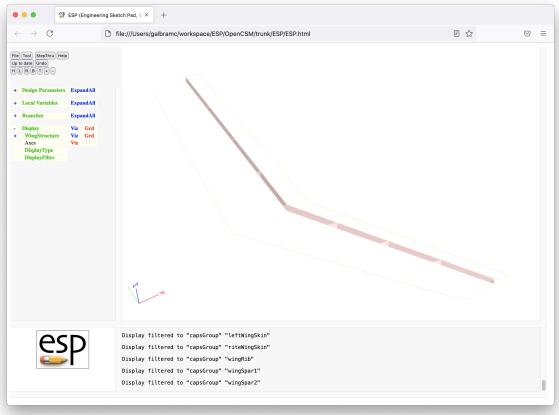
```
FACE HAS        tagType=spar tagIndex=1
SET             capsGroup=wingSpar1
SET             capsMesh=wingSpar1

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



session10/astros_1_ModalClamped.py

```
astros.input.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

session10/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 < " + astros.input.Proj_Name +  ".dat > " + astros.input.Proj_Name + ".out")

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

os.chdir(currentDirectory)       # Move back to top directory
```

ASTROS Cantilever Modal Analysis: Output

- Print the Eigen frequencies

session10/astros_1_ModalClamped.py

```
freqs = astros.output.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

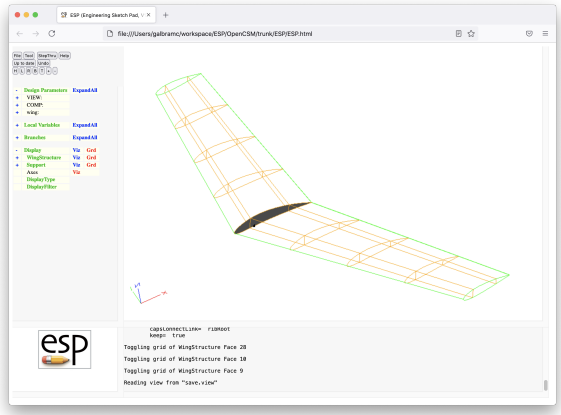
- Support connection on wing root rib `FACE/EDGE/NODE` using `capsConnectLink` and `capsConnect`

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
```

session10/astros_2_ModalSupport.py

```
wing.cfgpmtr.VIEW.Concept          = 0
wing.cfgpmtr.VIEW.SupportStructure = 1
wing.cfgpmtr.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
```

session10/astros_2_ModalSupport.py

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

# Set supports
support = {"dofSupport": 3}
astros.input.Support = {"ribRootPoint": support}

# Set constraints
constraint = {"dofConstraint" : 12456}
astros.input.Constraint = {"ribRootPoint": 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
```

session10/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.input.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

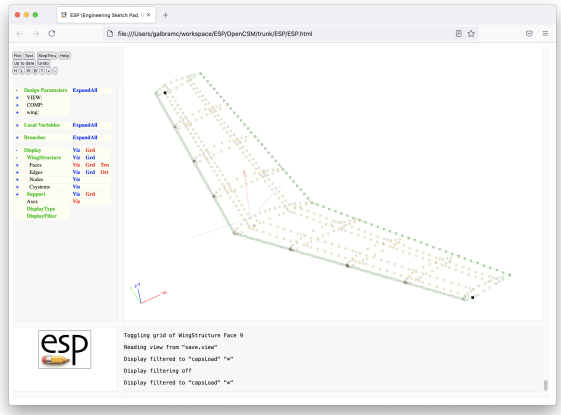
ASTROS Cantilever Static Analysis: Setup

- 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
```



session10/astros_3_StaticClamped.py

```
wing.cfgpmtr.VIEW.Concept           = 0
wing.cfgpmtr.VIEW.ClampedStructure = 1
wing.cfgpmtr.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
```

session10/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.input.Load = {"leftPointLoad": leftLoad,
                     "ritePointLoad": riteLoad}

# Set analysis type
astros.input.Analysis_Type = "Static"
```

ASTROS Cantilever Static Analysis: Output

- Print the displacements

session10/astros_3_StaticClamped.py

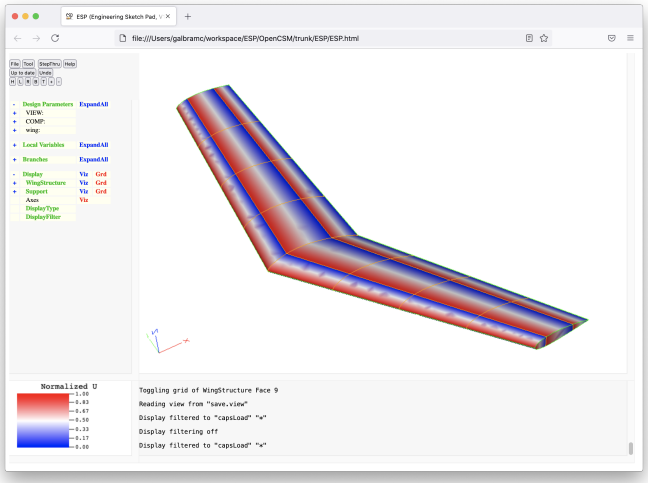
```
print ("\n--> Maximum displacements:")
print ("--> Tmax" , astros.output.Tmax )
print ("--> T1max", astros.output.T1max)
print ("--> T2max", astros.output.T2max)
print ("--> T3max", astros.output.T3max)
```

Composite Materials: Coordinate system

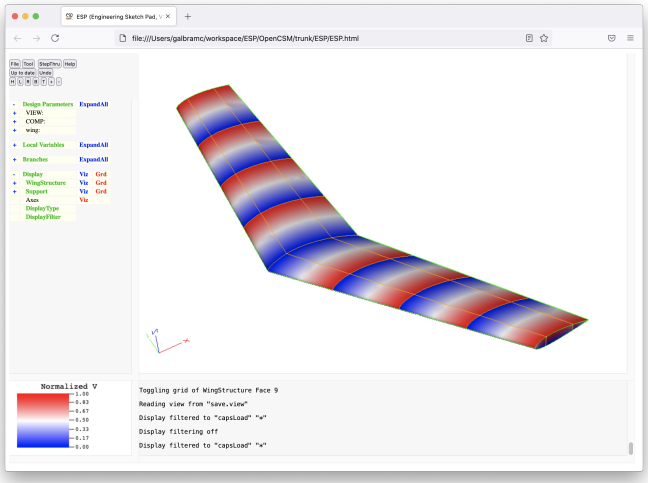
- Coordinate system `name` matches `capsGroup`

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



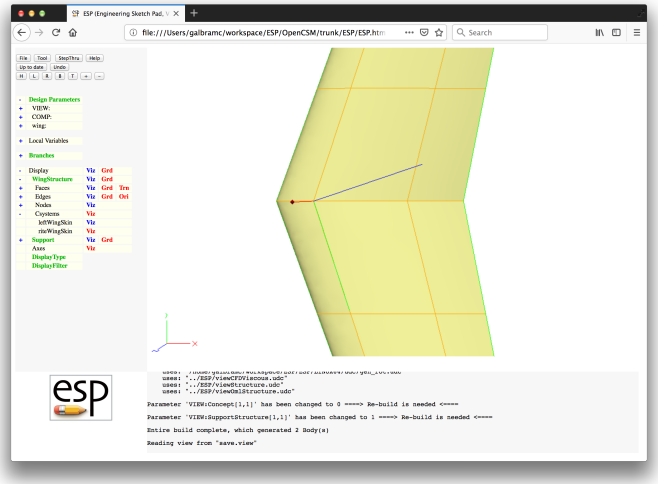
Normalized v-coordinates

Composite Materials: Coordinate system

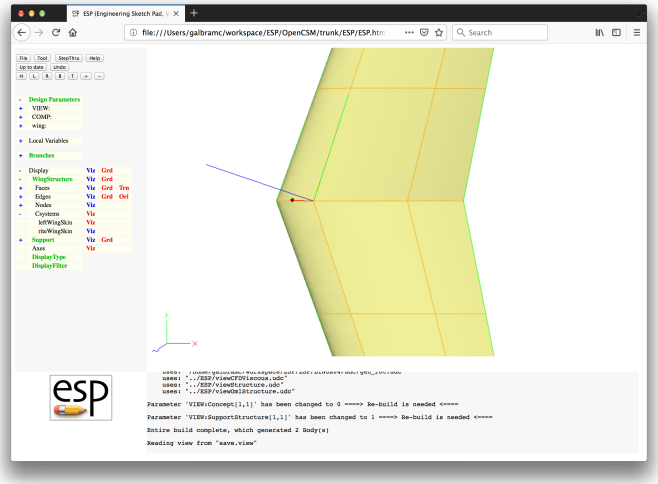
- Coordinate system `name` matches `capsGroup`

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

session10/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.input.Material = {"Aluminum"      : Aluminum,
                         "Graphite_epoxy": Graphite_epoxy}
```

Composite Materials: Property

- `CompositeOrientation` angles relative to `CSYSTEM`

session10/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.input.Property = {"leftWingSkin": skinShell,
                         "riteWingSkin": skinShell,
                         "wingRib"     :  ribShell,
                         "wingSpar1"   : sparShell,
                         "wingSpar2"   : sparShell}
```

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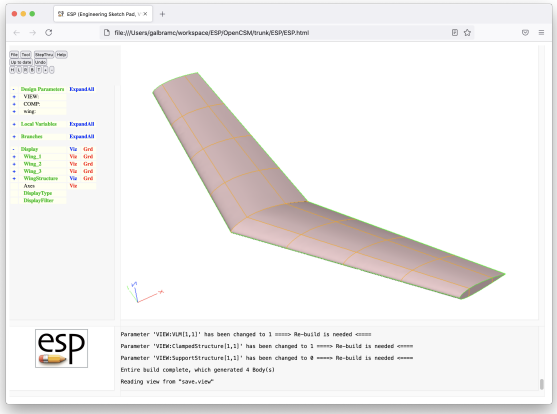
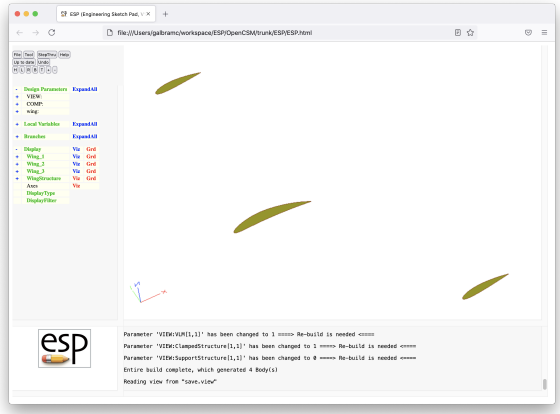
Flutter analysis with NASTRAN: Setup

- Cantilever aeroelastic flutter analysis



Structural body with full skin

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



VLM Aero bodies

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

session10/nastran_5_Flutter.py

```
# Change to Structures and VLM
wing.cfgpmtr.VIEW.Concept           = 0
wing.cfgpmtr.VIEW.VLM               = 1
wing.cfgpmtr.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
```

session10/nastran_5_Flutter.py

```
# Set analysis type
nastran.input.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.input.VLM_Surface = {"upperWing": wingVLM}
```

Suggested Exercises

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