Computational Aircraft Prototype Syntheses

Training Session 3
CAPS Analysis

ESP v1.18

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Overview

- Python Basics
  - Lists, Tuples and Dictionaries
- Accessing/modifying analysis values
  - set/getAnalysisVal
- Analysis execution and outputs
  - pre/postAnalysis
  - getAnalysisOutVal
- DIRTY/CLEAN process
  - Tracking changes to inputs that impact outputs
- `capsGroup` attribute
  - Connecting geometry with analysis properties
- Suggested Exercises

Python Basics: Lists

- List: ordered changeable collection. Allows duplicates.
- Created with square brackets []

```
thislist = ["apple", "banana", "banana", "cherry"]
print(thislist    ) # Prints "[’apple’, ’banana’, ’banana’, ’cherry’]"
print(thislist[ 0]) # Prints ’apple’
print(thislist[-1]) # Prints ’cherry’

thislist[1] = "pear" # Change the banana to a pear
thislist.append(42) # Append 42 to the end of the list

for fruit in thislist: # Print each fruit (and 42) in the list via item
    print(fruit)

for i in range(len(thislist)): # Print each fruit (and 42) in the list via index
    print(thislist[i])
```

For more examples: `www.w3schools.com/python/python_lists.asp`

Python Basics: Tuples

- Tuple: ordered unchangeable collection. Allows duplicates.
- Created with parenthesis ()

```
thistuple = ("apple", "banana", "banana", "cherry")
print(thistuple    ) # Prints "('apple', 'banana', 'banana', 'cherry')"
print(thistuple[ 0]) # Prints 'apple'
print(thistuple[-1]) # Prints 'cherry'

for fruit in thistuple: # Print each fruit in the tuple via item
    print(fruit)

for i in range(len(thistuple)): # Print each fruit in the tuple via index
    print(thislist[i])

thistuple[1] = "pear" # Runtime error
```

For more examples: `www.w3schools.com/python/python_tuples.asp`

Python Basics: Dictionaries

- Dictionary: unordered unchangeable indexed collection. No duplicates.
- Created with curly brackets {}
- key - value pairs separated by colon

```
thisdict = {
  "status" : "Don’t panic",
  "Dolphin": "So long, and thanks for all the fish.",
  42       : "The answer"
  "Years of thought" : 7.5e6
}
print(thisdict["status"]) # Prints ’Don’t panic’
print(thisdict[42]) # Prints ’The answer’

# Modify the answer
thisdict[42] = "The answer to the great question... Of life, the universe and everything..."

for key in thisdict: # Print each key in the dict
    print(key)

for key in thisdict:  # Print each value in the dict
    print(thisdict[key])
```

More examples: `www.w3schools.com/python/python_dictionaries.asp`

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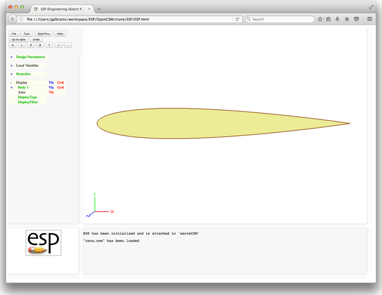
NACA Airfoil Geometry

session03/naca.csm

```
# NACA design paramters
DESPMTR   thick      0.12       #frac of local chord
DESPMTR   camber     0.00       #frac of local chord

# Construct the airfoil
UDPRIM  naca   Thickness thick   Camber  camber
    ATTRIBUTE capsAIM $xfoilAIM;tsfoilAIM
```

XFOIL
Subsonic Airfoil Development System



```
ESP has been initialized and is attached to 'serveCSM'
"naca.csm" has been loaded
```

Setting/accessing analysis values with pyCAPS

- Analysis values of an AIM are set or accessed with set/getAnalysisVal
- Available AIM analysis values listed in documentation

session03/xfoil_1_AnalysisVal.py

```
# Load xfoil aim
print ("\n==> Loading xfoilAIM")
xfoil = myProblem.loadAIM(aim = "xfoilAIM",
                          analysisDir = "workDir_xfoil_1")

# Set Mach number
xfoil.setAnalysisVal("Mach", 0.5 )

# Print the modified mach number
mach = xfoil.getAnalysisVal("Mach")
print("\n==> Modified Mach =", mach)
```

Setting/accessing analysis values with pyCAPS

- Analysis values can be tuples/lists and toggled

session03/xfoil_1_AnalysisVal.py

```
# Print the default value of None
print("\n==> Default Alpha =", xfoil.getAnalysisVal("Alpha"))

# Set Alpha number
xfoil.setAnalysisVal("Alpha", 2.5 )
print("\n==> Modified Alpha =", xfoil.getAnalysisVal("Alpha"))

# Set list of Alpha
xfoil.setAnalysisVal("Alpha", [0.0, 3.0, 5.0, 7.0, 8.0] )
print("\n==> Modified Alpha =", xfoil.getAnalysisVal("Alpha"))

# Unset Alpha back to None
xfoil.setAnalysisVal("Alpha", None )
print("\n==> Unset Alpha =", xfoil.getAnalysisVal("Alpha"))
```

- Available analysis values in xfoil AIM documentation

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Running analysis with pyCAPS: Inputs

- Load AIM and set analysis values

session03/xfoil_2_Analysis.py

```
print ("\n==> Loading xfoilAIM")
xfoil = myProblem.loadAIM(aim = "xfoilAIM",
                          analysisDir = "workDir_xfoil_2")

print ("\n==> Setting analysis values")
# Set Mach and Reynolds number
xfoil.setAnalysisVal("Mach", 0.5 )
xfoil.setAnalysisVal("Re", 1.0E6 )

# Set list of Alpha
xfoil.setAnalysisVal("Alpha", [0.0, 3.0, 5.0, 7.0, 8.0] )
```

Running analysis with pyCAPS: preAnalysis

- Run preAnalysis to generate xfoil input files

  session03/workDir_xfoil_2/caps.xfoil
  session03/workDir_xfoil_2/xfoilInput.txt

session03/xfoil_2_Analysis.py

```
print ("\n==> Loading xfoilAIM")
xfoil = myProblem.loadAIM(aim = "xfoilAIM",
                          analysisDir = "workDir_xfoil_2")
```

```
# Run AIM pre-analysis
print ("\n==> Running preAnalysis")
xfoil.preAnalysis()
```

Running analysis with pyCAPS: Execution

- Execute xfoil in session03/workDir_xfoil_2

session03/xfoil_2_Analysis.py

```
####### Run xfoil ####################
print ("\n\n==> Running xFoil......")

currentDirectory = os.getcwd() # Get current working directory
os.chdir(xfoil.analysisDir)    # Move into test directory

# Run xfoil via system call
os.system("xfoil < xfoilInput.txt > Info.out");

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

- `CAPS` currently does not execute analysis tools
- Driving program responsible for execution

Running analysis with pyCAPS: postAnalysis

- Run postAnalysis to indicate completion and parse output files

session03/xfoil_2_Analysis.py

```
# Run AIM post-analysis
print ("\n==> Running postAnalysis")
xfoil.postAnalysis()
```

- Get results from the analysis with getAnalysisOutVal

```
# Retrieve Alpha, Cl and Cd
print ("\n==> Retrieve analysis results")
Alpha = xfoil.getAnalysisOutVal("Alpha")
Cl    = xfoil.getAnalysisOutVal("CL")
Cd    = xfoil.getAnalysisOutVal("CD")

print()
print("--> Alpha =", Alpha)
print("--> Cl    =", Cl)
print("--> Cd    =", Cd)
```

Multi analysis with the same AIM: Run

- Helper function for running the analysis

session03/xfoil_3_Analysis.py

```
def run_xfoil(xfoil):
    # Run AIM pre-analysis
    print ("\n==> Running preAnalysis")
    xfoil.preAnalysis()

    ####### Run xfoil ####################
    print ("\n\n==> Running xFoil......")

    currentDirectory = os.getcwd() # Get current working directory
    os.chdir(xfoil.analysisDir)    # Move into test directory

    # Run xfoil via system call
    os.system("xfoil < xfoilInput.txt > Info.out");

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

    # Run AIM post-analysis
    print ("\n==> Running postAnalysis")
    xfoil.postAnalysis()
```

Multi analysis with the same AIM: Alpha

- Compute polar for a range of angles of attack

session03/xfoil_3_Analysis.py

```
print ("\n==> Setting analysis values")
# Set Mach and Reynolds number
xfoil.setAnalysisVal("Mach", 0.5 )
xfoil.setAnalysisVal("Re", 1.0E6 )

# Set list of Alpha
xfoil.setAnalysisVal("Alpha", [0.0, 3.0, 5.0, 7.0, 8.0] )

# Run xfoil
run_xfoil(xfoil)

# Retrieve Alpha, Cl and Cd
print ("\n==> Retrieve analysis results")
Alpha = xfoil.getAnalysisOutVal("Alpha")
Cl    = xfoil.getAnalysisOutVal("CL")
Cd    = xfoil.getAnalysisOutVal("CD")

print()
print("--> Alpha =", Alpha)
print("--> Cl    =", Cl)
print("--> Cd    =", Cd)
```

Multi analysis with the same AIM: CL

- Switch to compute polar for a range of lift coefficients

session03/xfoil_3_Analysis.py

```
# Unset Alpha, otherwise it will be included in the next analysis
xfoil.setAnalysisVal("Alpha", None )

# Set specific Cl values instead
xfoil.setAnalysisVal("CL", [0.0, 0.1, 0.15, 0.3, 0.4] )

# Run xfoil
run_xfoil(xfoil)

# Retrieve Alpha, Cl and Cd
print ("\n==> Retrieve analysis results")
Alpha = xfoil.getAnalysisOutVal("Alpha")
Cl    = xfoil.getAnalysisOutVal("CL")
Cd    = xfoil.getAnalysisOutVal("CD")

print()
print("--> Alpha =", Alpha)
print("--> Cl    =", Cl)
print("--> Cd    =", Cd)
```

Analysis with geometric changes: Setup

- Setup analysis values

session03/xfoil_4_Camber.py

```
# Load geometry [.csm] file
filename = "naca.csm"
print ("\n==> Loading geometry from file \""+filename+"\"...")
naca = myProblem.loadCAPS(filename)

# Load xfoil aim
print ("\n==> Loading xfoilAIM")
xfoil = myProblem.loadAIM(aim = "xfoilAIM",
                          analysisDir = "workDir_xfoil_4")

print ("\n==> Setting analysis values")
# Set Mach and Reynolds number
xfoil.setAnalysisVal("Mach", 0.5 )
xfoil.setAnalysisVal("Re", 1.0E6 )

# Set list of Alpha
xfoil.setAnalysisVal("Alpha", [0.0, 1.0, 3.0] )
```

Analysis with geometric changes: Camber

- Execute sequence of cambers

session03/xfoil_4_Camber.py

```
# List of cambers to analyze
Cambers = [0.00, 0.01, 0.04, 0.07]

Alpha = []; Cl = []; Cd = []
for camber in Cambers:
    # Modify the camber
    naca.setGeometryVal("camber", camber)

    # Run xfoil
    run_xfoil(xfoil)

    # Append Alpha, Cl and Cd
    print ("\n==> Retrieve analysis results")
    Alpha.append(xfoil.getAnalysisOutVal("Alpha"))
    Cl.append(xfoil.getAnalysisOutVal("CL"))
    Cd.append(xfoil.getAnalysisOutVal("CD"))

print()
print("--> Cambers =", Cambers)
print("--> Alpha   =", Alpha)
print("--> Cl      =", Cl)
print("--> Cd      =", Cd)
```

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CAPS `CLEAN/DIRTY` Process

- Calling setGeometryVal marks geometry as `DIRTY`
  - Geometry always built just-in-time

- Calling setAnalysisVal or setGeometryVal marks the AIM as `DIRTY`
- CAPS does not execute analysis, cannot execute just-in-time
- Errors reported accessing getAnalysisOutVal if AIM is `DIRTY`
- Errors reported running preAnalysis if AIM is `CLEAN`
  - Avoids inefficiencies with unnecessary calls to preAnalysis

CAPS Successful Execution

- Execution without errors

session03/xfoil_5_CleanDirty.py

```
print("\n1. No Errors ", "-"*80)

# Set Mach and Reynolds number
xfoil.setAnalysisVal("Mach", 0.5 )
xfoil.setAnalysisVal("Re", 1.0E6 )

# Set list of Alpha
print("\n==> Setting alpha sequence")
xfoil.setAnalysisVal("Alpha", [0.0, 3.0, 5.0, 7.0, 8.0] )

# Run xfoil
run_xfoil(xfoil)

# Retrieve Cl
Cl = xfoil.getAnalysisOutVal("CL")
print("\n--> Cl    =", Cl)
```

CAPS DIRTY Analysis

- Trying call getAnalysisOutVal with DIRTY AIM due to setAnalysisVal

session03/xfoil_5_CleanDirty.py

```
print("\n2. DIRTY AnalysisVal Error ", "-"*80)

# Set a new alphas
print("\n==> Setting new alpha sequence")
xfoil.setAnalysisVal("Alpha", [1.0, 2.0] )

# Try to retrieve Cl without executing pre/postAnalysis
print("\n==> Attempting to get Cl")
try:
    Cl = xfoil.getAnalysisOutVal("CL")
    print("\n--> Cl    =", Cl)
except CAPSError as e:
    print("\n==> CAPSError =", e)
```

CAPS DIRTY Geometry

- Trying call getAnalysisOutVal with `DIRTY` AIM due to setGeometryVal

session03/xfoil_5_CleanDirty.py

```
print("\n3. DIRTY GeometryVal Error ", "-"*80)

# Modify a geometric parameter
print("\n==> Modifying camber")
myProblem.geometry.setGeometryVal("camber", 0.07)

# Try to retrieve Cl without executing pre/postAnalysis
print("\n==> Attempting to get Cl")
try:
    Cl = xfoil.getAnalysisOutVal("CL")
    print("\n--> Cl    =", Cl)
except CAPSError as e:
    print("\n==> CAPSError =", e)
```

CAPS DIRTY postAnalysis

- Trying to call getAnalysisOutVal without calling postAnalysis

session03/xfoil_5_CleanDirty.py

```
print("\n4. DIRTY pre- but no postAnalysis Error ", "-"*80)

# Modify mach number
print("\n==> Modifying Mach")
xfoil.setAnalysisVal("Mach", 0.3 )

# Run AIM pre-analysis
print ("\n==> Running preAnalysis but not running postAnalysis")
xfoil.preAnalysis()

# Retrieve Cl
print("\n==> Attempting to get Cl")
try:
    Cl = xfoil.getAnalysisOutVal("CL")
    print("\n--> Cl    =", Cl)
except CAPSError as e:
    print("\n==> CAPSError =", e)
```

CAPS CLEAN Error

- Calling preAnalysis with a `CLEAN` AIM

session03/xfoil_5_CleanDirty.py

```
print("\n5. CLEAN Error ", "-"*80)

# Don't modify any analysis or geometry values

try:
    # Run xfoil
    run_xfoil(xfoil)
except CAPSError as e:
    print("\n==> CAPSError =", e)
```

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The `capsGroup` attribute – Masstran Wing

`capsGroup` attribute

- Tags groups of `BODY`/`FACE`/`EDGE`/`NODE`
    - Entities with same `capsGroup` value are in the group
- Specific use of `capsGroup` is AIM dependent

session03/masstran_6_f118_Wing.py

```
filename = "f118-C.csm"
print ("\n==> Loading geometry from file \""+filename+"\"...")
myProblem.loadCAPS(filename, verbosity=0)

# Load the masstran aim with the wing
masstran = myProblem.loadAIM(aim = "masstranAIM",
                             analysisDir = "workDir_masstranWing",
                             capsIntent="wing")
```

The capsGroup attribute – Masstran Wing

- Wing FACEs tagged with "wing:faces"
- masstranAIM material and properties for "wing:faces"

session03/f118-C.csm

```
# Wing
SET      wing:span     sqrt(wing:aspect*wing:area)
SET      wing:chord    wing:area/wing:span

BOX  wing:xroot  -wing:span/2  wing:zroot   wing:chord  wing:span  wing:chord*wing:thick
    ATTRIBUTE capsGroup  $wing:faces
```

session03/masstran_6_f118_Wing.py

```
# Define material properties
unobtainium = {"density" : 7850}

# Set the material
masstran.setAnalysisVal("Material", ("Unobtainium", unobtainium))

# Define shell property
shell = {"propertyType"      : "Shell",
         "material"          : "Unobtainium",
         "membraneThickness" : 0.2}

# Associate the shell property with capsGroups defined on the geometry
masstran.setAnalysisVal("Property", ("wing:faces", shell))
```

The capsGroup attribute – Masstran F-118C

- `capsGroups` on all `FACEs`

session03/f118-C.csm

```
BOX  wing:xroot  -wing:span/2  wing:zroot   wing:chord  wing:span  wing:chord*wing:thick
    ATTRIBUTE capsGroup  $wing:faces
```

```
BOX  htail:xroot  -htail:span/2  htail:zroot   htail:chord  htail:span  htail:chord*htail:thick
    ATTRIBUTE capsGroup  $htail:faces
```

```
BOX  vtail:xroot  0  vtail:zroot   vtail:chord  vtail:chord*vtail:thick  vtail:span
    ATTRIBUTE capsGroup  $vtail:faces
```

```
BOX  0  -fuse:width/2  -fuse:height/2   fuse:length  fuse:width  fuse:height
SELECT face 1
    ATTRIBUTE capsGroup  $fuse:nose
SELECT face 2
    ATTRIBUTE capsGroup  $fuse:tail
SELECT face 3
    ATTRIBUTE capsGroup  $fuse:side
SELECT face 4
    ATTRIBUTE capsGroup  $fuse:side
SELECT face 5
    ATTRIBUTE capsGroup  $fuse:side
SELECT face 6
    ATTRIBUTE capsGroup  $fuse:side
```

The capsGroup attribute – Masstran F-118C

- Properties assigned to capsGroups

session03/masstran_7_f118.py

```
# Define material properties
unobtainium = {"density" : 7850}
madeupium   = {"density" : 6890}

# Set the materials
masstran.setAnalysisVal("Material", [("Unobtainium", unobtainium),
                                     ("Madeupium", madeupium)])

# Define shell properties
shell_1 = {"propertyType"      : "Shell",
           "material"          : "unobtainium",
           "membraneThickness" : 0.2}

shell_2 = {"propertyType"      : "Shell",
           "material"          : "madeupium",
           "membraneThickness" : 0.3}

# Associate the shell property with capsGroups defined on the geometry
masstran.setAnalysisVal("Property", [("wing:faces" , shell_1), ("htail:faces", shell_1),
                                     ("fuse:nose"  , shell_1), ("fuse:tail"  , shell_1),
                                     ("vtail:faces", shell_2), ("fuse:side"  , shell_2)])
```

The `capsGroup` attribute – AVL Plane Vanilla

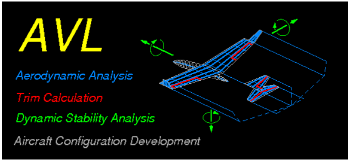
- AVL - Vortex Lattice Method: Geometry defined by airfoils
- `capsGroup` groups airfoils into surfaces

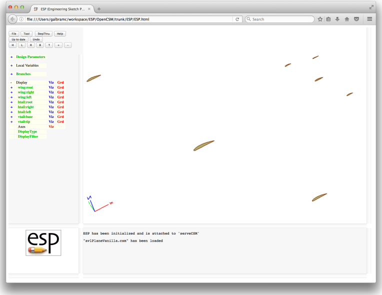
session03/avlPlaneVanilla.csm

```
UDPRIM    naca  Thickness wing:thick  Camber wing:camber
SCALE     wing:croot
ROTATEX   90        0         0
TRANSLATE wing:xroot    0    wing:zroot
   ATTRIBUTE capsGroup          $Wing
```

```
UDPRIM    naca  Thickness wing:thick  Camber wing:camber
SCALE     htail:croot
ROTATEX   90        0         0
TRANSLATE htail:xroot    0    htail:zroot
   ATTRIBUTE capsGroup $Htail
```

```
UDPRIM    naca  Thickness vtail:thick
SCALE     vtail:croot
TRANSLATE vtail:xroot    0    vtail:zroot
   ATTRIBUTE capsGroup $Vtail
```


AVL
Aerodynamic Analysis
Trim Calculation
Dynamic Stability Analysis
Aircraft Configuration Development



```
ESP has been initialized and is attached to 'serveCSM'
"avlPlaneVanilla.csm" has been loaded
```

The capsGroup attribute – AVL Plane Vanilla

- VLM meshing parameters defined via `capsGroups`

session03/avl_8_PlaneVanilla.py

```
# Load avl aim
print ("\n==> Loading avlAIM")
avl = myProblem.loadAIM(aim = "avlAIM",
                        analysisDir = "workDir_avl")

print ("\n==> Setting analysis values")
avl.setAnalysisVal("Alpha", 1.0)

# Set meshing parameters for each surface
wing = {"numChord"     : 4,
        "numSpanTotal" : 24}

htail = {"numChord"     : 4,
         "numSpanTotal" : 16}

vtail = {"numChord"     : 4,
         "numSpanTotal" : 10}

# Associate the surface parameters with capsGroups defined on the geometry
avl.setAnalysisVal("AVL_Surface", [("Wing" , wing ),
                                   ("Htail", htail),
                                   ("Vtail", vtail)])
```

Suggested Exercises

Thickness

- Plot airfoil polars for a range of airfoil thicknesses
    - Start from a copy of session03/xfoil_4_Camber_Plot.py

New Shells and Material

- Change `capsGroup` value for the top and bottom faces of the fuselage for F-118C (either the same or two different values)
- Starting with session03/masstran_7_f118.py, create a new shell and/or material for the newly created `capsGroup`(s)

Suggested Exercises Cont.

F-118C CG Location

- Using session03/masstran_7_f118.py, create an array of F-118C CG x-locations by modifying the wing:xroot location

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