Engineering Sketch Pad (ESP)

Training Session 3
Solids Fundamentals (2)

John F. Dannenhoffer, III
jfdannen@syr.edu
Syracuse University

Bob Haimes
haimes@mit.edu
Massachusetts Institute of Technology

updated for v1.19

Overview

- Miscellaneous Branches
- Manipulating the Stack
  - GROUP
  - STORE, RESTORE
- Grown Bodys
  - EXTRUDE
  - REVOLVE
  - RULE
  - BLEND
- Creating a Waffle
  - UDPRIM WAFFLE
- Homework Exercises

Miscellaneous Branches (1)

- `SET` — set the value of a Local Variable to the given expression
- `MARK` — push a Mark onto the Stack
- `SELECT` — select entity for which @-parameters are evaluated
  - see "help" for details
- `PROJECT` — find the first projection from a given point (in space) in a given direction

Miscellaneous Branches (2)

- `DUMP` — write file that contains the Body (not Group) on the top of the Stack
  - if `remove` is not zero, the Body is popped off the Stack
  - if `toMark` is not zero, all Bodys since the Mark are written
- The types of files that can be written by `DUMP` include:
  - `.brep` or `.BREP` — `OpenCASCADE` output
  - `.bstl` or `.BSTL` — binary stereolithography output
  - `.egads` or `.EGADS` —`EGADS` output
  - `.egg` or `.EGG` — EGG restart output
  - `.igs` or `.IGS` — IGES output
  - `.sens` or `.SENS` — sensitivity information
  - `.step` or `.STEP` — STEP output
  - `.stl` or `.STL` — ASCII stereolithography output
  - `.stp` or `.STP` — STEP output
  - `.tess` or `.TESS` — ASCII tessellation output
  - `.ugrid` or `.UGRID` — ASCII AFLR3 output

Manipulating the Stack (1)

- During the build process, `OpenCSM` maintains a last-in-first-out (LIFO) "Stack" that can contain Bodys, Marks, and Sketches.
- The `.csm` statements are executed in a stack-like way, taking their inputs from the Stack and depositing their results onto the Stack.
- Bodys can be grouped with the `GROUP` statement
  - all the Bodys back to the Mark (or the beginning of the Stack) are put into a single Group
  - some operations, such as the transformations, `ATTRIBUTE`, `STORE`, and `DUMP` operate on all Bodys in the Group simultaneously
  - Bodys and be ungrouped by giving `GROUP` a negative argument

Manipulating the Stack (2)

- The Group on the top of the Stack can be "popped" off the Stack with a `STORE $name index` command
  - if the `name` is alpha-numeric, the Group is stored in a named storage location, with the given `index` (from 0 to 99)
  - if the `name` is a dot (.), the Group is not stored (just popped off the Stack)
  - if the `name` is two dots (..), all the Groups back to the Mark are popped off the Stack (and not stored)
  - if the `name` is three dots (...), everything is popped off the Stack

Manipulating the Stack (3)

- Groups can be read from a named storage location and "pushed" onto the Stack with the `RESTORE $name index` command
- The `RESTORE` command is considered a primitive, so its Attributes are put on all the Bodys and all their Faces
- `RESTORE .` now duplicates the Body (not Group) on the top of the stack

Manipulating the Stack (4)

- Assume that the Stack contains: 5 7 9 12 (top)
- If one wants to reverse the top two Bodys, use
  - `STORE temp 1`
    - Stack now contains: 5 7 9
    - storage `temp 1` contains 12
  - `STORE temp 2`
    - Stack now contains: 5 7
    - storage `temp 2` contains 9
  - `RESTORE temp 1`
    - Stack now contains: 5 7 12
  - `RESTORE temp 2`
    - Stack now contains: 5 7 12 9

Manipulating the Stack (5)

- Assume that the Stack contains: 5 7 9 12 (top)
- If one wants to put a mark between the 7 and 9, use
  - `STORE temp 1`
    - Stack now contains: 5 7 9
    - storage `temp 1` contains 12
  - `STORE temp 2`
    - Stack now contains: 5 7
    - storage `temp 2` contains 9
  - `MARK`
    - Stack now contains: 5 7 mark
  - `RESTORE temp 2`
    - Stack now contains: 5 7 mark 9
  - `RESTORE temp 1`
    - Stack now contains: 5 7 mark 9 12

Miscellaneous Branches (6)

- If you want to duplicate the Group on the top of the Stack, use `STORE` and `RESTORE`
- Depending on the value of `keep` in the `STORE` command, the Group on the top of the Stack is either kept (like a "copy") or popped off the Stack (like a "cut")
  - not using the `keep` option to duplicate the Body on the top of the Stack

    ```
    STORE   temp
    RESTORE temp
    RESTORE temp
    ```

  - using the `keep` option to duplicate the Body on the top of the Stack

    ```
    STORE   temp 0 1
    RESTORE temp
    ```

Setting Array Values

- Use the `DIMENSION` statment to set the size of the array
  - `DIMENSION` creates a Branch, so its arguments can be any expression
- Use the `SET` statement to define the values
  - if name of array is given, set all the values
    - if more values are given than needed, excess are ignored
    - if fewer values are given than needed, last value is repeated

```
CFGPMTR   numRows 3
CONPMTR   numCols 2
DIMENSION array   numRows numCols
SET       array   "5;2"
```

creates: array = [5, 2, 2, 2, 2, 2]

- A single array element can be assigned with

```
SET       array[2,1]  3
```

Grown Primitives (from SheetBodys)

- Pops one or more SheetBodys from the Stack
- Pushes the resultant Body onto the Stack
- Supported grown features include:
  - `EXTRUDE` — in a given direction for a given distance
  - `REVOLVE` — around a given axis for a given angular displacement
  - `RULE` — connect all the SheetBodys/WireBodys back to the Mark by straight lines
    - the first and/or last Xsect can be a NodeBody
  - `BLEND` — connect all the SheetBodys/WireBodys back to the Mark with smooth curves
    - the first and/or last Xsect can be a NodeBody
    - at the bounding Nodes, the user can specify the radius of curvature in two orthogonal directions
  - `SWEEP` — a SheetBody/WireBody along a given WireBody
    - this is often problematic in `OpenCASCADE`
  - `LOFT` — similar to `BLEND`, but with less control

Grown Primitives (from WireBodys)

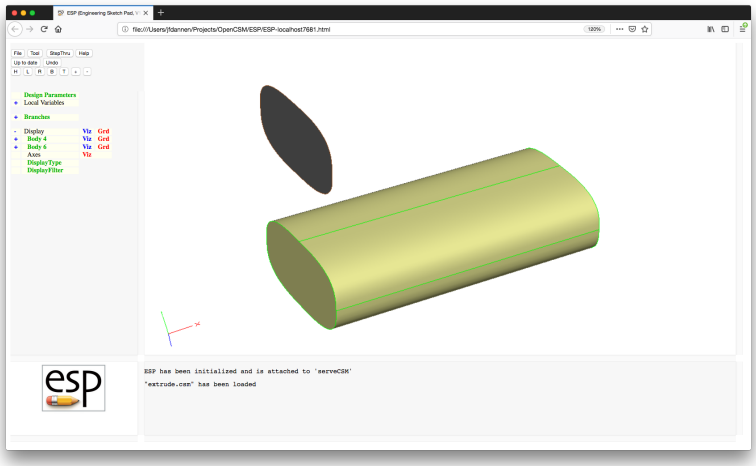
- Pops one or more WireBodys from the Stack
- Pushes the resultant Body onto the Stack
- Supported grown features include:
  - `EXTRUDE` — in a given direction for a given distance
  - `REVOLVE` — around a given axis for a given angular displacement
  - `RULE` — connect all the WireBodys back to the Mark by straight lines
    - the first and/or last Xsect can be a NodeBody
  - `BLEND` — connect all the WireBodys back to the Mark with smooth curves
    - the first and/or last Xsect can be a NodeBody
    - at the bounding Nodes, the user can specify the radius of curvature in two orthogonal directions

Grown Primitives (from NodeBodys)

- Pops one or more NodeBodys from the Stack
- Pushes the resultant Body onto the Stack
- Supported grown features include:
  - `EXTRUDE` — in a given direction for a given distance
  - `REVOLVE` — around a given axis for a given angular displacement
  - `RULE` — connect all the NodeBodys back to the Mark by straight lines
  - `BLEND` — connect all the NodeBodys back to the Mark with smooth curves

Grown Primitive — EXTRUDE

Note: Original Xsect (SheetBody) and result of EXTRUDE are shown

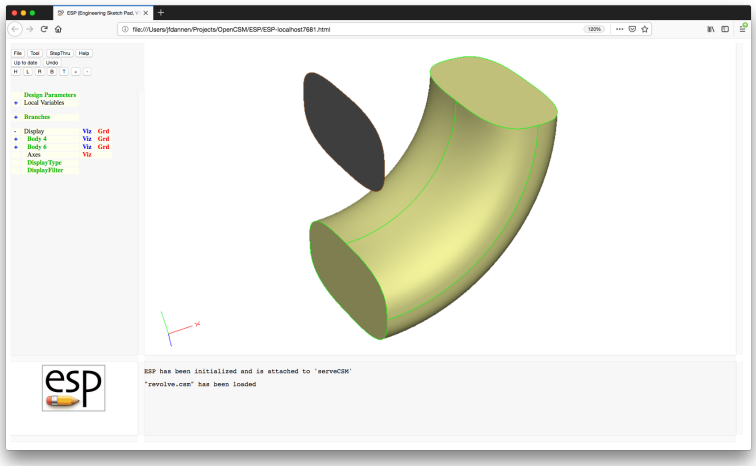



```
# extrude

UDPRIM  supell rx 2 ry_n 1 ry_s 1 n 3
ROTATEY 90 0 0
STORE  sections

RESTORE sections
TRANSLATE 0 4 0

RESTORE sections
EXTRUDE 8 0 0

END
```

- Face-order is: (1) orig Xsect, (2) copy of Xsect, (3) Face from first Xsect Edge, (4) Face from second Xsect Edge, . . .

Grown Primitive — REVOLVE

Note: Original Xsect (SheetBody) and result of REVOLVE are shown



```
# revolve

UDPRIM  supell rx 2 ry_n 1 ry_s 1 n 3
ROTATEY 90 0 0
STORE  sections

RESTORE sections
TRANSLATE 0 4 0

RESTORE sections
REVOLVE 0 4 0  0 0 1  90

END
```

- Face-order is: (1) orig Xsect, (2) copy of Xsect, (3) Face from first Xsect Edge, (4) Face from second Xsect Edge, . . .

Special Note on REVOLVE

- To revolve a Xsect to make a body of revolution:
  - do not use:

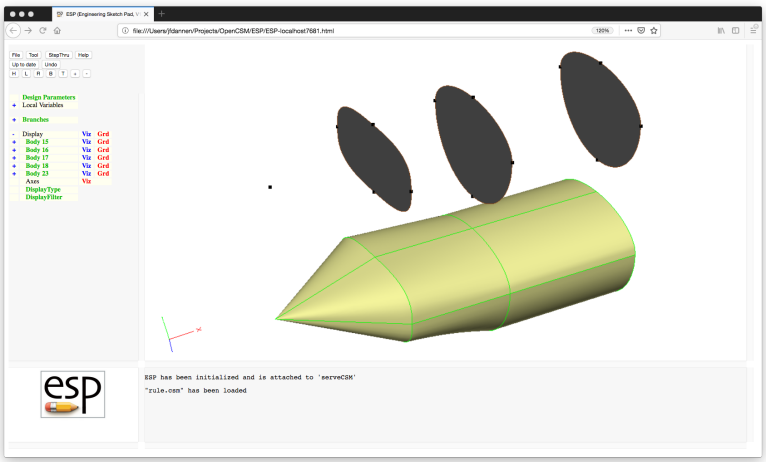
```
# make whole Body
REVOLVE    0 0 0    0 1 0    360
```

  - use instead:

```
# make half on Body
REVOLVE    0 0 0    0 1 0    180

# mirror for second half
STORE      half    0    1
RESTORE    half    0
MIRROR     0    0    1    0

# put it all together
JOIN       0     0
```

Grown Primitive — RULE

Note: Original Xsects (SheetBodys) and result of RULE are shown

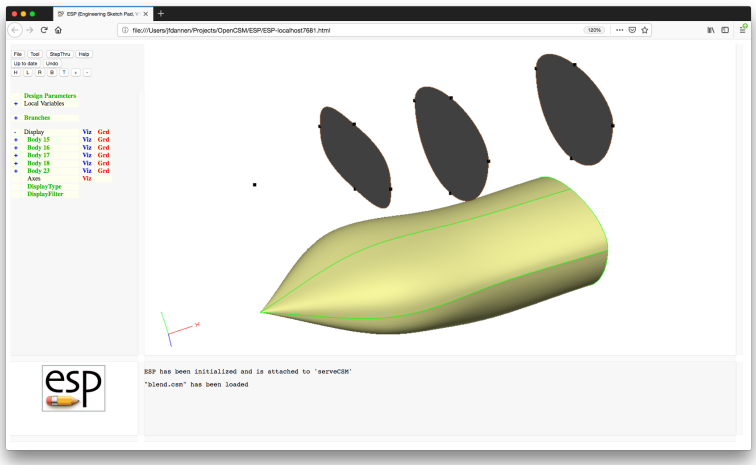



```
# rule

MARK
   POINT  0 0 0

   UDPRIM  supell rx 2 ry_n 1 ry_s 1 n 3
   ROTATEY 90 0 0
   TRANSLATE 3 0 0

   UDPRIM  supell rx 2 ry_n 1 ry_s 2
   ROTATEY 90 0 0
   TRANSLATE 6 0 0

   UDPRIM  supell rx 2 ry_n 1 ry_s 2
   ROTATEY 90 0 0
   TRANSLATE 10 0 0
GROUP
STORE  sections

RESTORE sections
TRANSLATE 0 4 0

MARK
   RESTORE sections
RULE

END
```

- Face-order on later slide

Grown Primitive — BLEND

Note: Original Xsects (SheetBodys) and result of BLEND are shown



```
# blend

MARK
   POINT  0 0 0

   UDPRIM  supell rx 2 ry_n 1 ry_s 1 n 3
   ROTATEY 90 0 0
   TRANSLATE 3 0 0

   UDPRIM  supell rx 2 ry_n 1 ry_s 2
   ROTATEY 90 0 0
   TRANSLATE 6 0 0

   UDPRIM  supell rx 2 ry_n 1 ry_s 2
   ROTATEY 90 0 0
   TRANSLATE 10 0 0
GROUP
STORE  sections

RESTORE sections
TRANSLATE 0 4 0

MARK
   RESTORE sections
BLEND

END
```

- Face-order on later slide

Bodys Produced by RULE and BLEND

- If the first and last Xsects are both WireBodys
  - a SheetBody is produced that is open on both ends
- If the first or last Xsect is a WireBody
  - a SheetBody is produced that is open on one end and closed on the other
- Otherwise
  - a SolidBody is produced

Face-order for RULE and BLEND

- (1) first Xsect (or empty if POINT)
- (2) last Xsect (or empty if POINT)
- (3) Face from first Xsect Edge between first and second Xsects
- (4) Face from first Xsect Edge between second and third Xsectss
- ...
- (n) Face from second Xsect Edge between first and second Xsects
- ...

RULE and BLEND

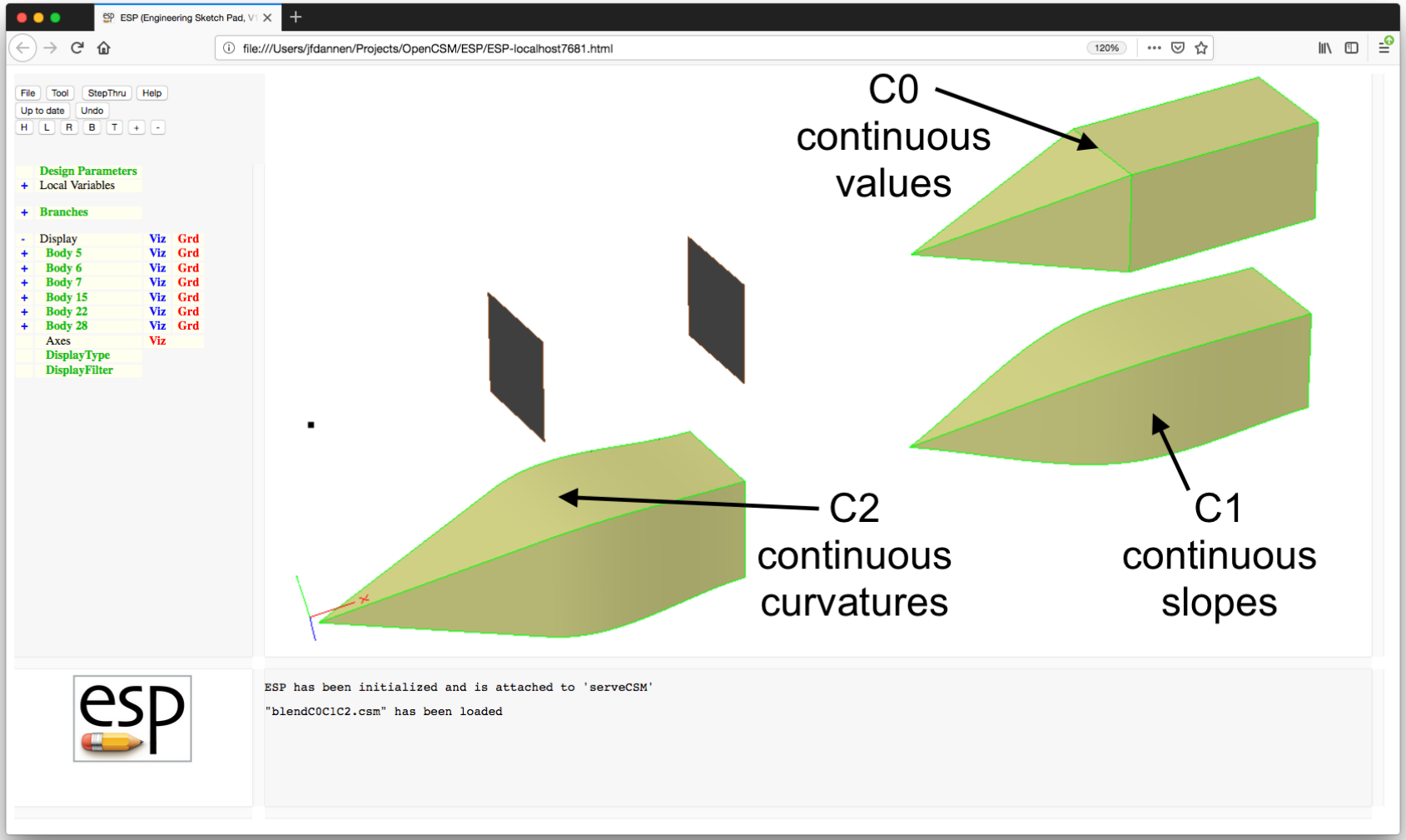
- RULE and BLEND require that all Xsects have the same number of Segments, ordered in the same way
  - new Faces are made by combining all the first Segments, ...
- BLEND allows user-selectable continuity in blend direction
  - C2 - curvature continuity (the default)
  - C1 - slope continuity (obtained with Face repeated once)
  - C0 - value continuity (obtained with Face repeated twice)
- Xsects can be automatically reordered to help eliminate twist by setting **reorder** to a non-zero value
  - positive to start from first Xsect
  - negative to start from last Xsect
- Users can manually reorder Xsects with the REORDER command (applied to a Xsect)
  - Reordering only changes the order of Segments, not their shapes

BLEND Continuity (1)

```
# blendC0C1C2

# original Xsects (top left)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
GROUP
TRANSLATE -3 +1 0

# Body with C0 at second Xsect (top rite)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1
   UDPRIM box  dy 1  dz 1
   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
BLEND
TRANSLATE +3 +1 0
```

```
# Body with C1 at second Xsect (bottom left)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1
   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
BLEND
TRANSLATE -3 -1 0

# Body with C2 at second Xsect (bottom rite)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
BLEND
TRANSLATE +3 -1 0

END
```

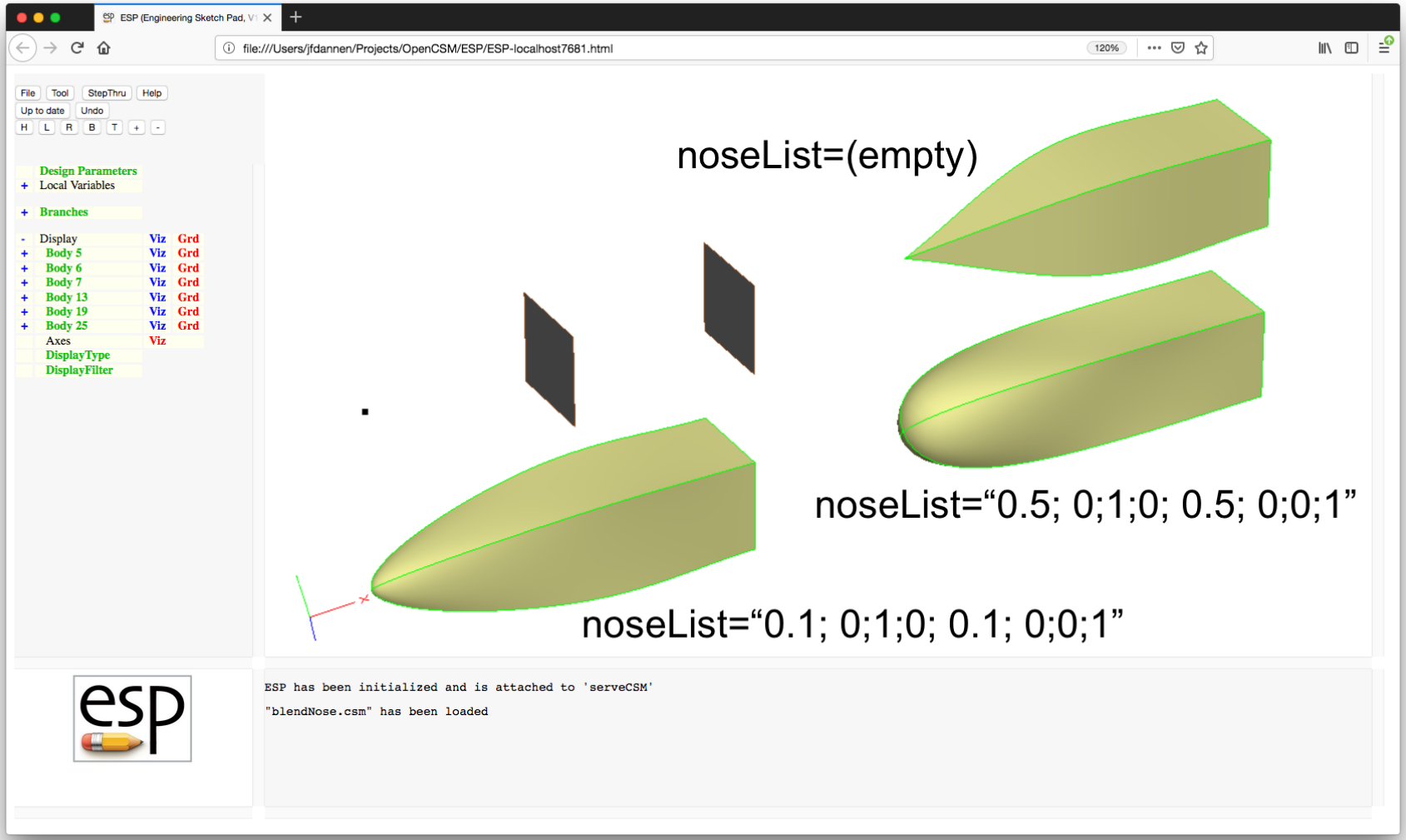
BLEND Continuity (2)



BLEND Nose/Tail Treatment (1)

```
# blendC0C1C2

# original Xsects (top left)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
GROUP
TRANSLATE -3 +1 0

# Body with pointed nose (top rite)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
BLEND
TRANSLATE +3 +1 0

# Body with slightly rounded nose (bottom left)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
BLEND "0.1; 0;1;0; 0.1; 0;0;1"
TRANSLATE -3 -1 0

# Body with rounded nose (bottom rite)
MARK
   POINT  -2  0  0

   UDPRIM box  dy 1  dz 1

   UDPRIM box  dy 1  dz 1
   TRANSLATE +2 0 0
BLEND "0.5; 0;1;0; 0.5; 0;0;1"
TRANSLATE +3 -1 0

END
```

BLEND Nose/Tail Treatment (2)



BLEND Wingtip Treatement (1)

- If the first Xsect is a SheetBody with 2 or 3 Edges and the `begList` contains 2 entries:
  - `begList[1]` = -1
  - `begList[2]` = the aspect ratio of an approximate ellipse that spans between the first and second Xsect Edge
- The same applies to the last Xsect and `endList`

BLEND Wingtip Treatement (2)

Building a Waffle (1)

- Called with `.csm` statement:
  `UDPRIM waffle depth <number> filename <name_of_file>`
- Valid statements in file are:
  - `CPOINT` — create a construction point (not in final waffle)
  - `CLINE` — create a construction line (not in final waffle)
  - `POINT` — create a waffle point
  - `LINE` — create one or more waffle segments
  - `PATBEG/PATEND` — create a pattern (loop)
- Keywords can be in lowercase or UPPERCASE
- Coordinates of existing point `<pname>` are given by
  - `x@<pname>` and `y@<pname>`

Building a Waffle (2)

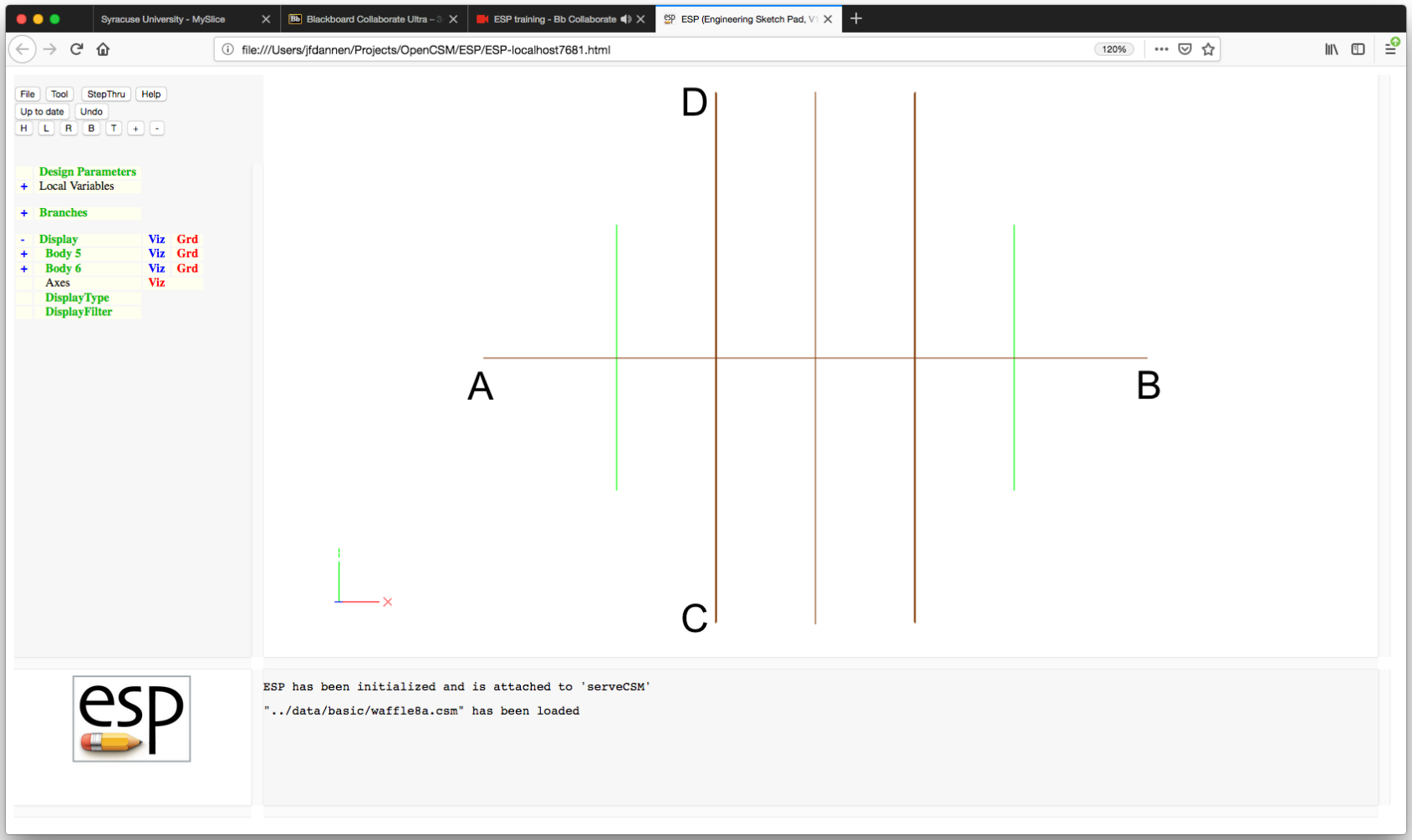
- Variants of `CPOINT` and `POINT`
  - `POINT <pname> AT <xloc> <yloc>`
    - create point at `<xloc,yloc>`
  - `POINT <pname> ON <lname> FRAC <fracDist>`
    - creates point on `<lname>` at given fractional distance
  - `POINT <pname> ON <lname> XLOC <x>`
    - creates point on `<lname>` at given `<x>`
  - `POINT <pname> ON <lname> YLOC <y>`
    - creates point on `<lname>` at given `<y>`
  - `POINT <pname> ON <lname> PERP <pname2>`
    - creates point on `<lname>` that is closest to `<pname2>`
  - `POINT <pname> ON <lname> XSECT <lname2>`
    - creates point at intersection of `<lname>` and `<lname2>`
  - `POINT <pname> OFF <lname> <dist> <pname2>`
    - creates point `<dist>` to the left of `<lname>` at `<pname2>`

Building a Waffle (3)

- Variants of `CLINE` and `LINE`
  - `LINE . <pname1> <pname2> <attrName1=attrValue1>...`
    - creates unnamed line between `<pname1>` and `<pname2>` with given attribute(s) (if any)
  - `LINE <lname> <pname1> <pname2> <attrName1=attrValue1>`
    - creates line named `<lname>` between `<pname1>` and `<pname2>` with given attribute(s) (if any)

Waffle Example (1)

SolidBody in green; Waffle in brown



Waffle Example (2)

```
# SolidBody
CYLINDER  0  0  0  3  0  0  1
STORE     SolidBody

# get bounding box of SolidBody
RESTORE   SolidBody
SET       xmin  @xmin
SET       xmax  @xmax
SET       ymin  @ymin
SET       ymax  @ymax
SET       zmin  @zmin
SET       zmax  @zmax
STORE     .
```

Waffle Example (3)

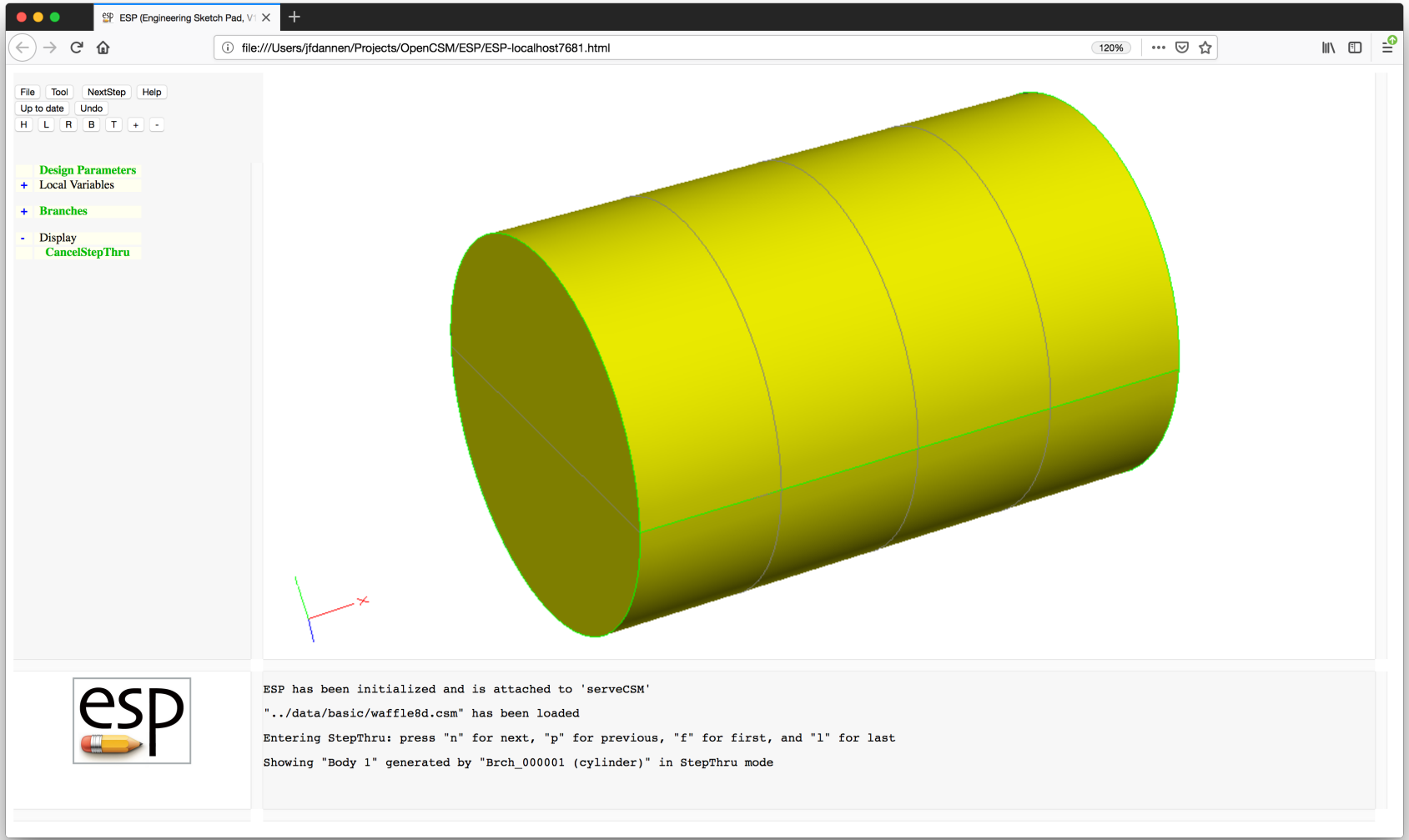
```
# Waffle (centered on SolidBody)
UDPRIM    waffle   filename <<   depth zmax-zmin+2
   POINT  A AT  xmin-1  (ymin+ymax)/2
   POINT  B AT  xmax+1  (ymin+ymax)/2
   LINE   AB  A  B  type=symmetry

   PATBEG  i  3
      POINT  C AT   xmin+i/4*(xmax-xmin) ymin-1
      POINT  D AT   xmin+i/4*(xmax-xmin) ymax+1
      LINE   .  C  D  type=!$bulkhead_+i
   PATEND
>>
TRANSLATE 0  0  zmin-1
STORE     Waffle
```

Waffle Example (4)

```
# score the SolidBody by the Waffle and extract Faces
RESTORE   SolidBody
RESTORE   Waffle
SUBTRACT
EXTRACT   0

# generate the internal structure
RESTORE   SolidBody
RESTORE   Waffle
INTERSECT

# put them together
UNION

END
```

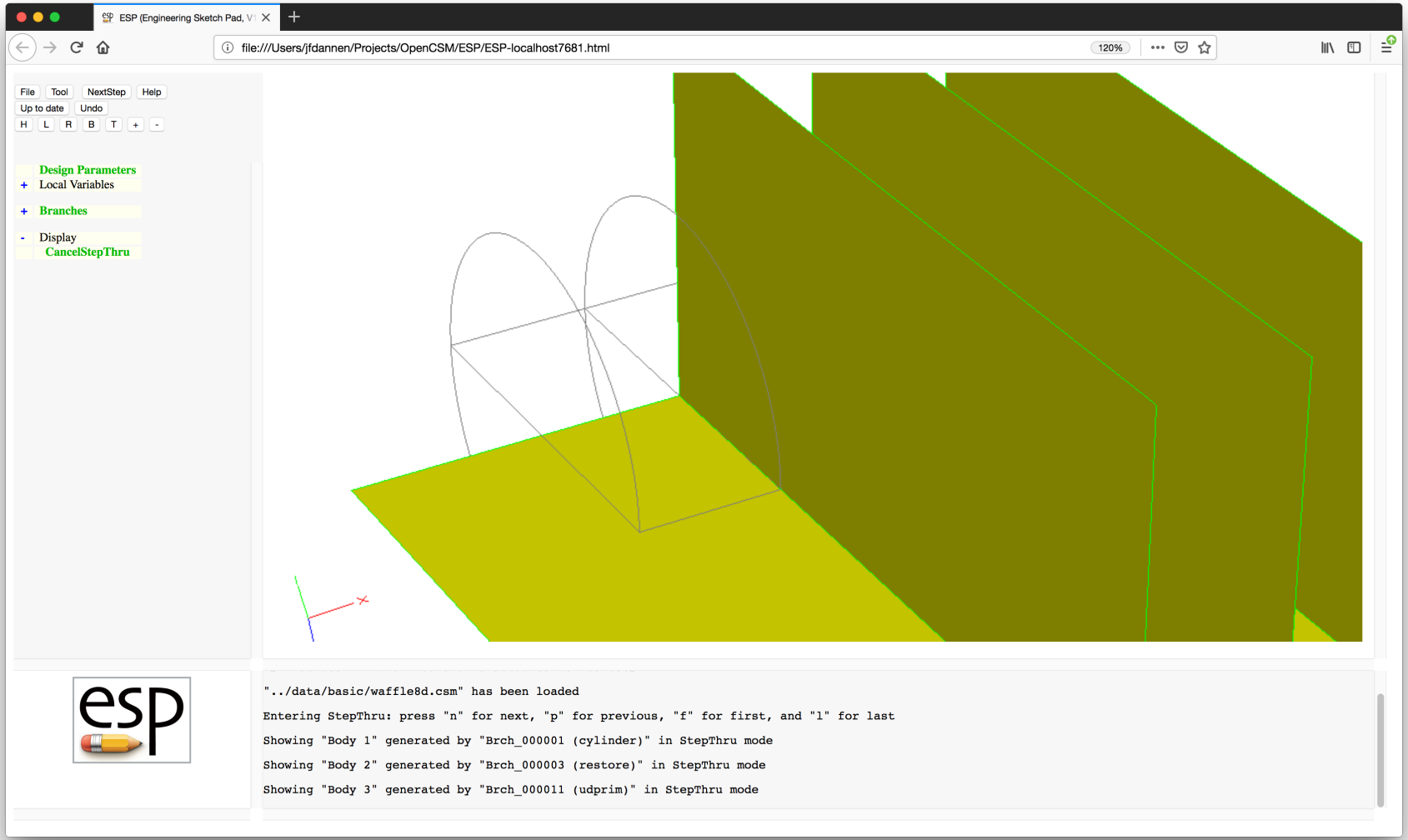
Waffle Example (5)

Original SolidBody
(Grey lines are only part of final configuration.)



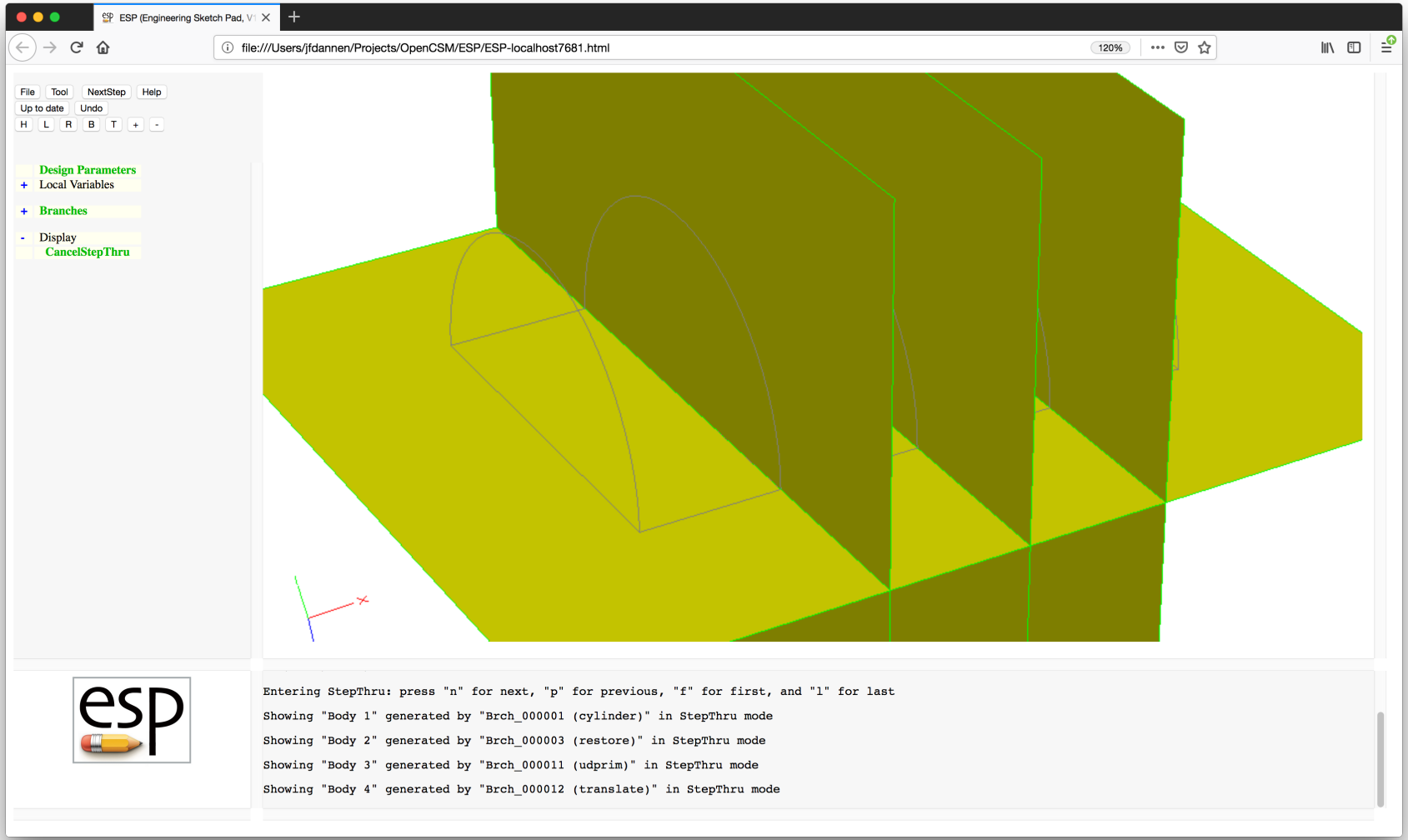
Waffle Example (6)

Original Waffle



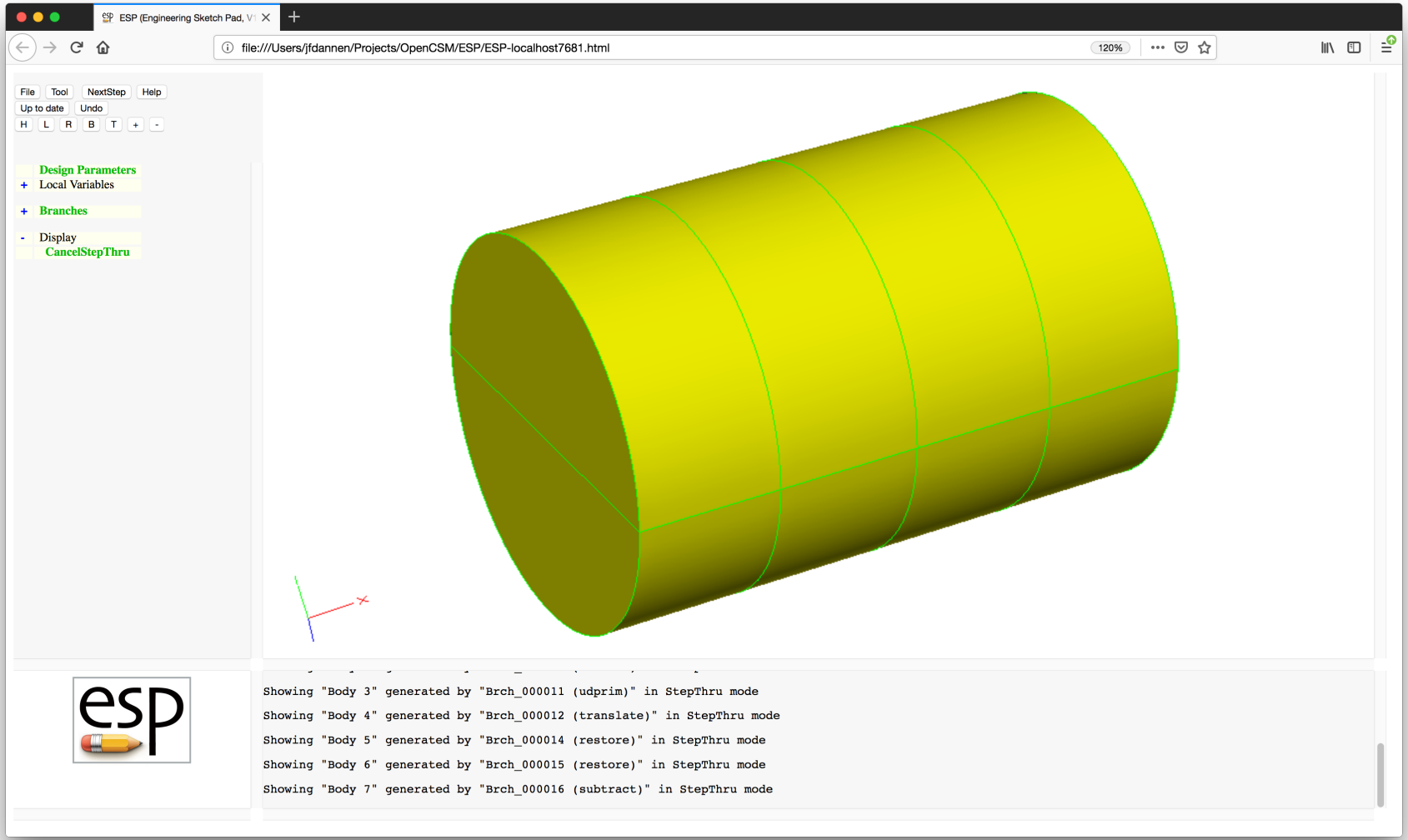
Waffle Example (7)

After TRANSLATing the Waffle



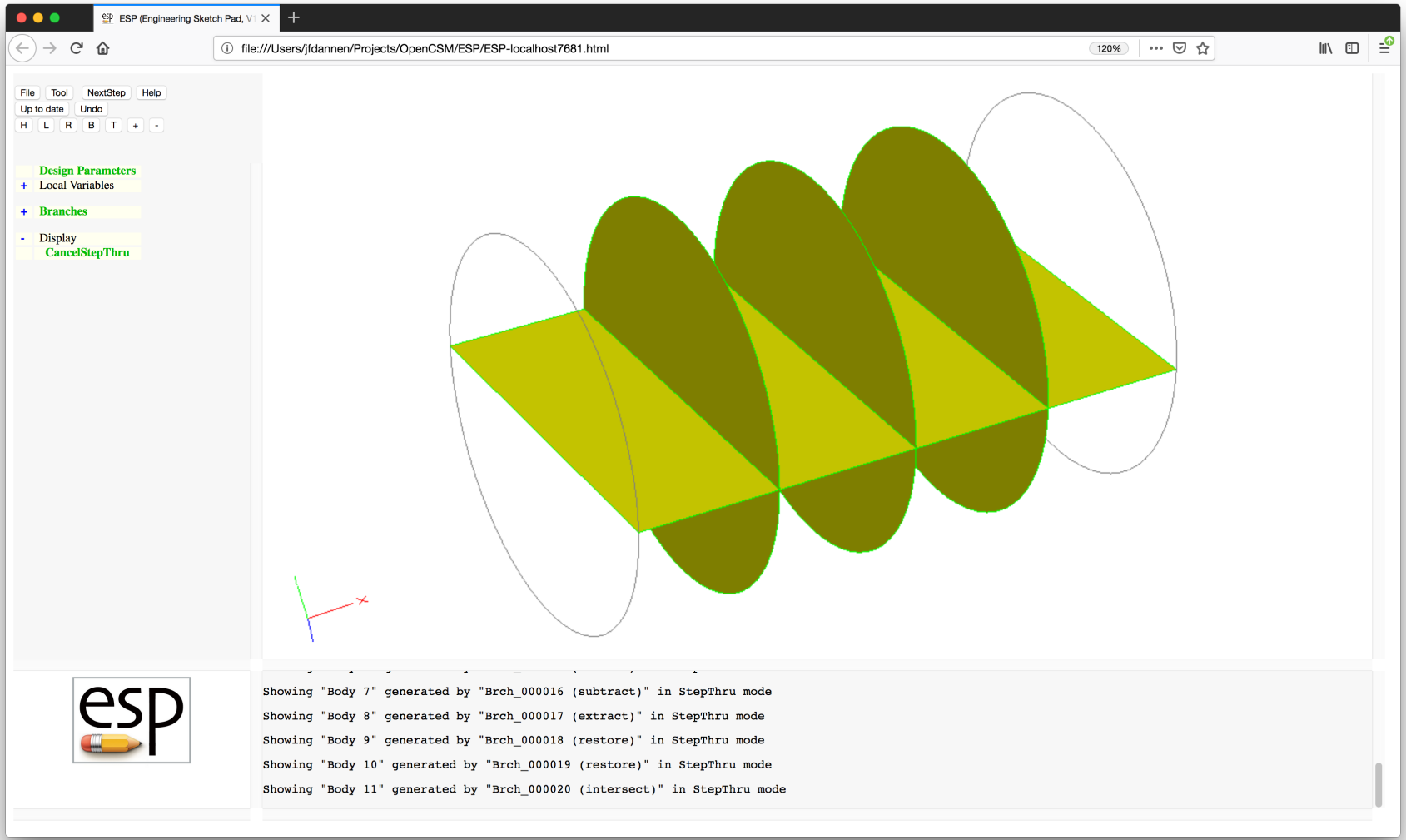
Waffle Example (8)

After SUBTRACTion of Waffle from SolidBody



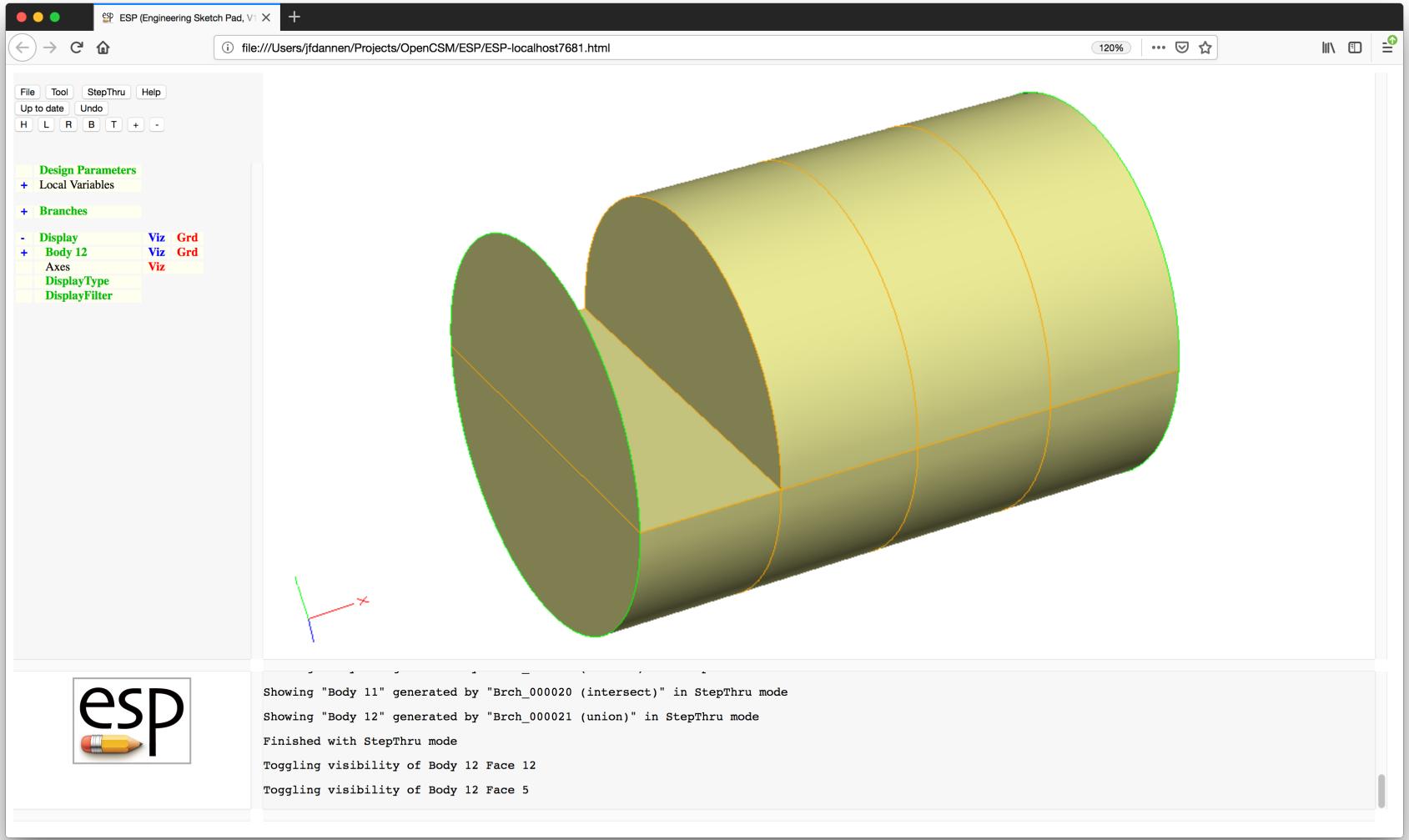
Waffle Example (9)

After INTERSECTion of SolidBody and Waffle

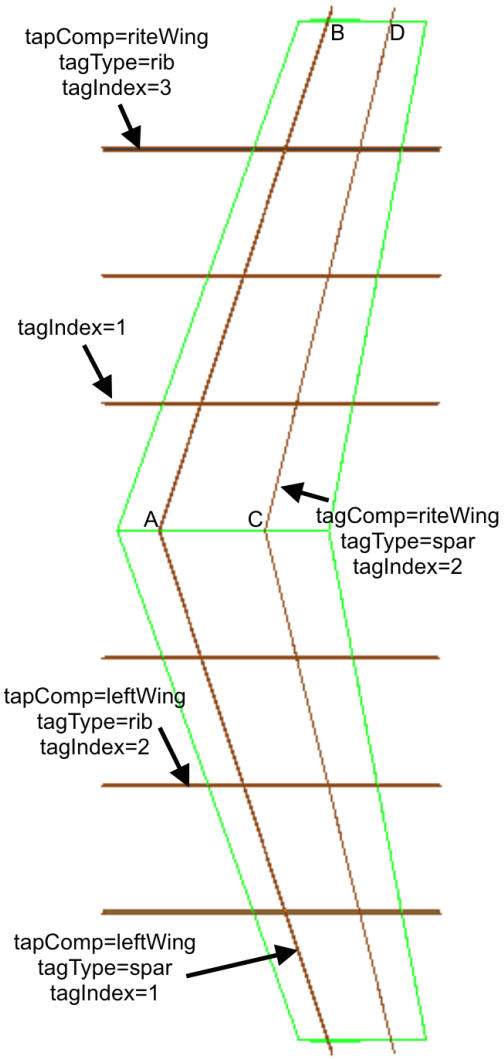


Waffle Example (10)

After `UNION` of scored SolidBody and interior Waffle (One Face shown transparent to see some of the internal structure.)

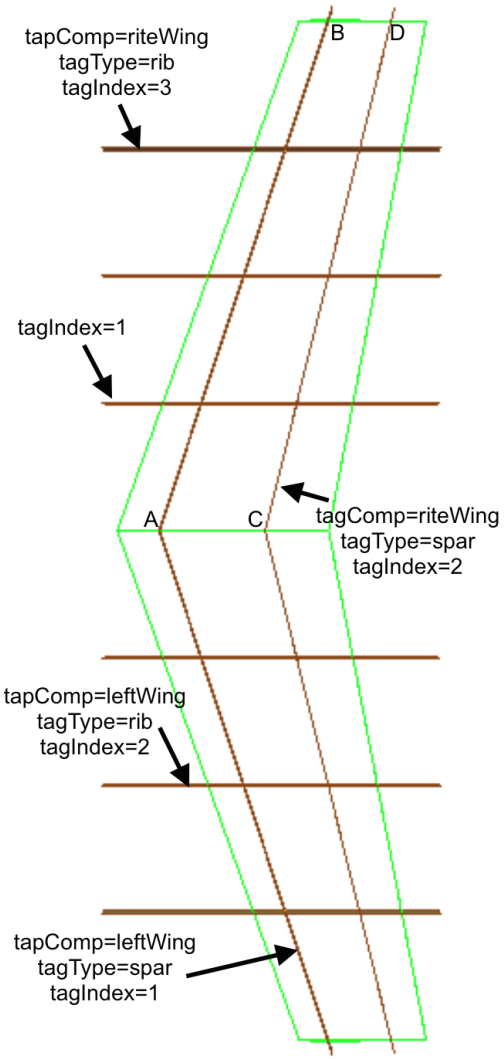


Waffle for wing3 (1)



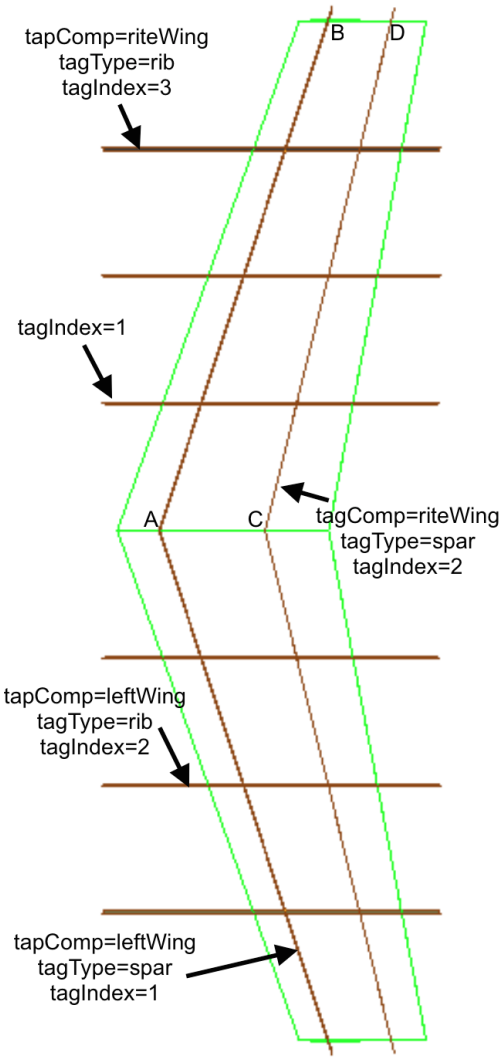

```
SET       xmin        @xmin-0.1
SET       xmax        @xmax+0.1
SET       ymin        0
SET       ymax        @ymax+0.1
SET       zmin        @zmin-0.1
SET       zmax        @zmax+0.1
STORE     .

UDPARG    waffle      depth wing:nrib     # ensures rebuild
UDPARG    waffle      depth wing:spar1
UDPARG    waffle      depth wing:spar2
UDPRIM    waffle      depth zmax-zmin  filename <<

# construction lines for spars
CPOINT A    AT          0+wing:spar1*croot 0
CPOINT B    AT  wing_xtip+wing:spar1*ctip  wing_ytip
CPOINT C    AT          0+wing:spar2*croot 0
CPOINT D    AT  wing_xtip+wing:spar2*ctip  wing_ytip

CLINE  AB       A  B
CLINE  CD       C  D
```

Waffle for wing3 (2)




```
# rite spars
POINT  E   ON  AB   YLOC  ymin
POINT  F   ON  AB   YLOC  ymax
LINE   EF  E   F  tagComp=riteWing  tagType=spar tagIndex=1

POINT  G   ON  CD   YLOC  ymin
POINT  H   ON  CD   YLOC  ymax
LINE   GH  G   H  tagComp=riteWing  tagType=spar tagIndex=2

# rite ribs
PATBEG  irib  wing:nrib
    CPOINT  I  AT  xmin  wing_ytip*irib/(wing:nrib+1)
    CPOINT  J  AT  xmax  y@I
    LINE    .  I J tagComp=riteWing tagType=rib ...
                          tagIndex=!val2str(irib,0)

PATEND
```

Waffle for `wing3` (3)




```
# left spars
POINT  E   AT  x@E  -y@E
POINT  F   AT  x@F  -y@F
LINE   EF  E   F  tagComp=leftWing  tagType=spar tagIndex=1

POINT  G   AT  x@G  -y@G
POINT  H   AT  x@H  -y@H
LINE   GH  G   H  tagComp=leftWing  tagType=spar tagIndex=2

# left ribs
PATBEG  irib  wing:nrib
    CPOINT  I  AT  xmin  -wing_ytip*irib/(wing:nrib+1)
    CPOINT  J  AT  xmax  y@I
    LINE    .  I J tagComp=leftWing tagType=rib ...
                          tagIndex=!val2str(irib,0)

PATEND
>>
```

Homework Exercises

- Simple wing
- Simple fuselage
  - OML (outer mold line)
  - structure
- Starter files are in `$ESP_ROOT/training/ESP/data/session03`

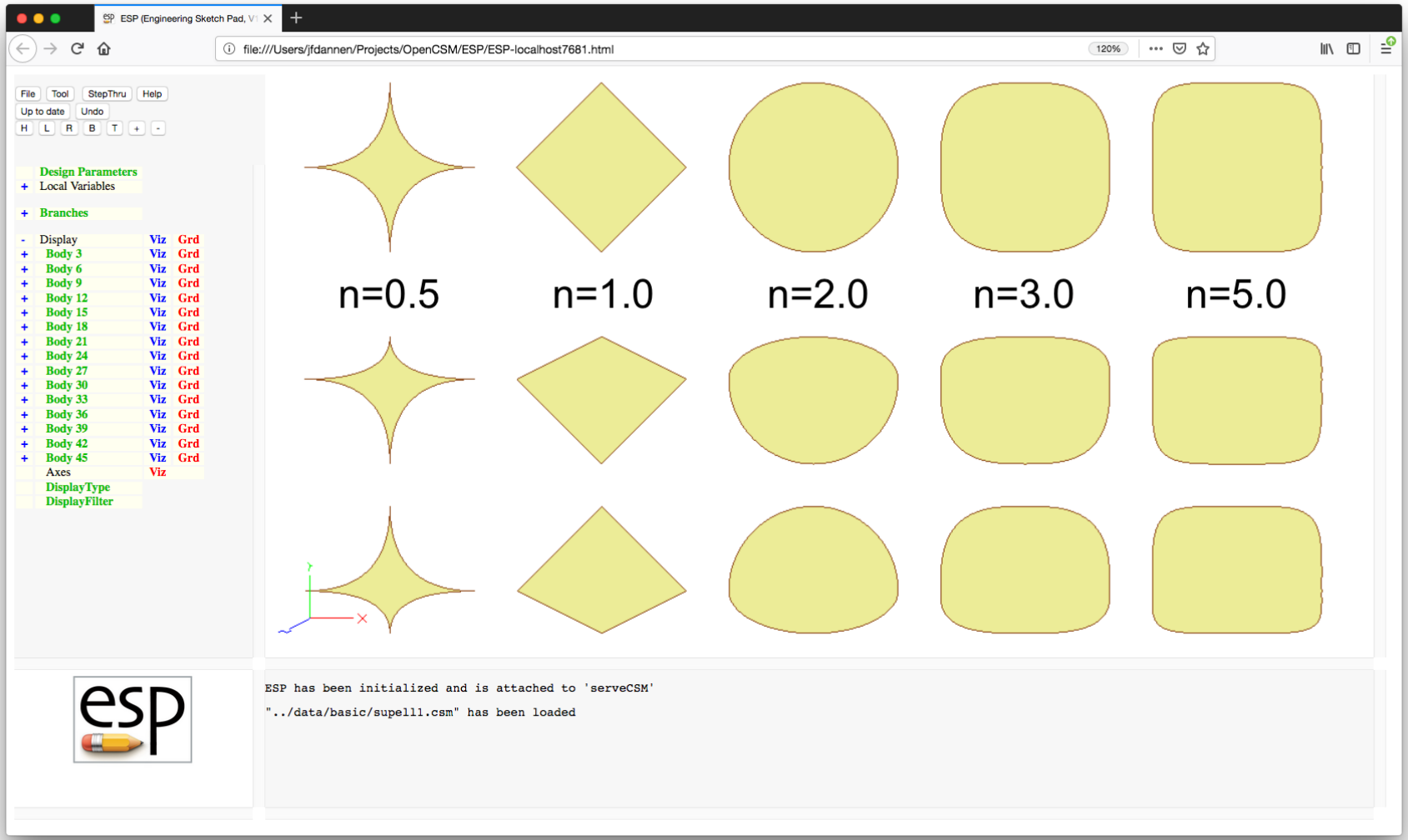
Creating NACA Airfoils

Generated with `UDPRIM naca: thickness camber`

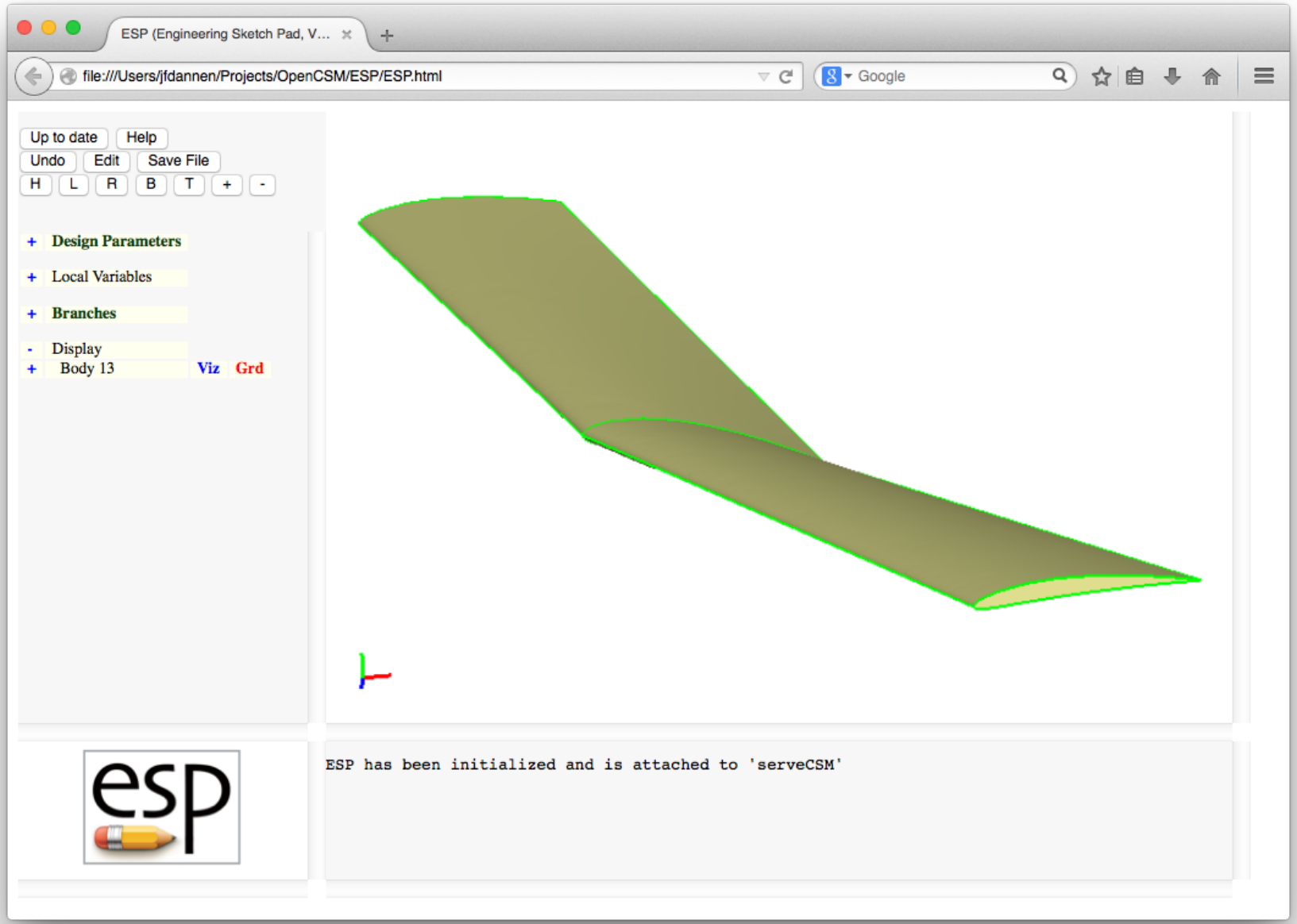
```
# naca

UDPRIM naca thickness 0.00 camber 0.04
TRANSLATE -2 0 0

UDPRIM naca thickness 0.12 camber 0.00

UDPRIM naca thickness 0.12 camber 0.04
TRANSLATE +2 0 0

END
```

Generated with UDPRIM supell: rx, ry, n

Generated with $ESP_ROOT/data/basic/supell1.csm



Simple Wing (1)



Simple Wing (2)

Xroot	X-coordinate of root leading edge	0.00
Yroot	Y-coordinate of root leading edge	0.00
Zroot	Z-coordinate of root leading edge	0.00
croot	chord of root	2.00
troot	thickness/chord of root	0.12
mroot	camber/chord of root	0.04
aroot	angle of attack of root (deg)	7.50
Xtip	X-coordinate of tip leading edge	0.50
Ytip	Y-coordinate of tip leading edge	0.25
Ztip	Z-coordinate of tip leading edge	8.00
ctip	chord of tip	1.75
ttip	thickness/chord of tip	0.08
mtip	camber/chord of tip	0.04
atip	angle of attack of tip (deg)	-5.00

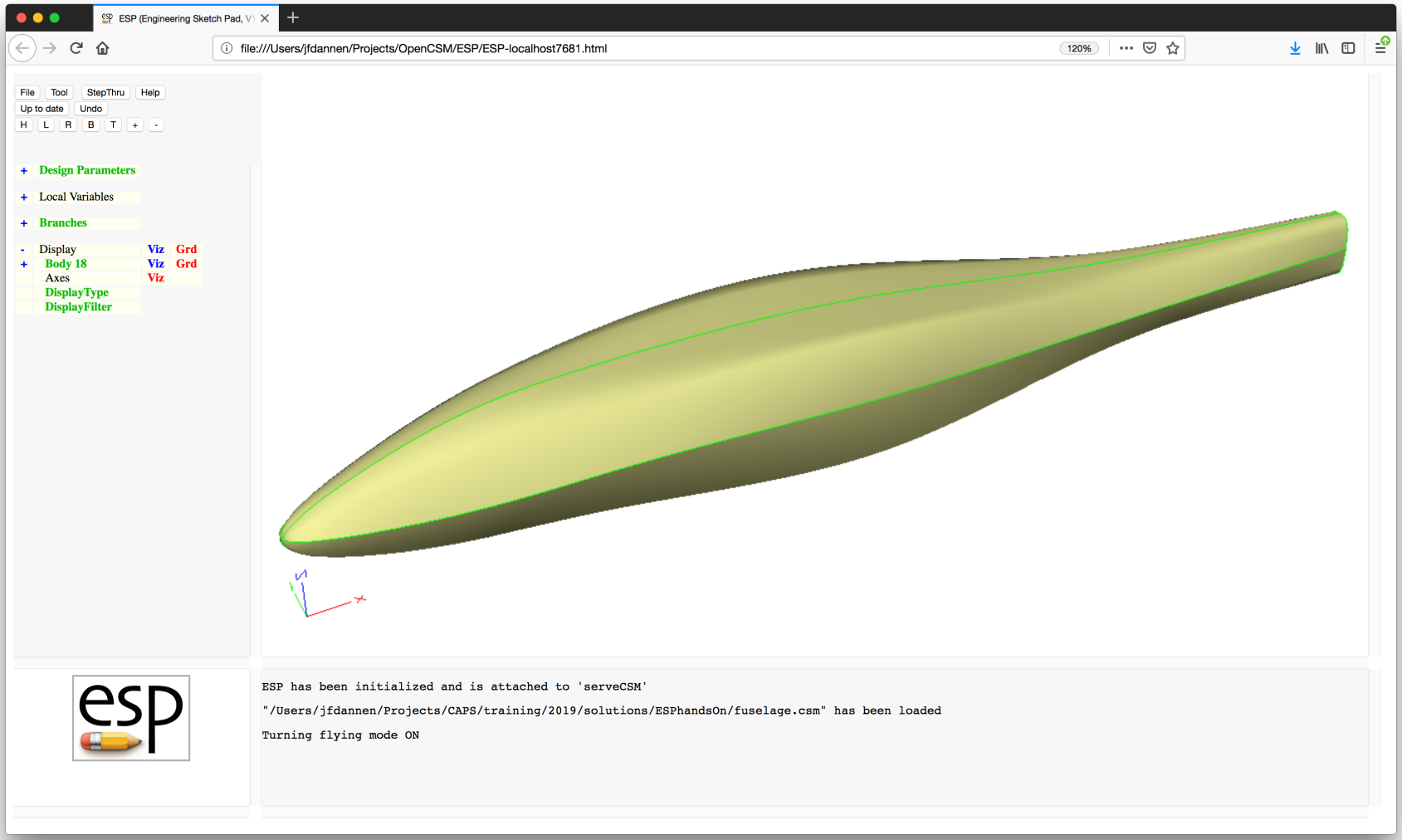
Simple Wing (3)

- What happens if you switch from `RULE` to `BLEND`?
- What happens if we change the sequence of transformations from `SCALE`, `ROTATEZ`, `TRANSLATE` to `ROTATEZ`, `SCALE`, `TRANSLATE`?
- What happens if we do the `TRANSLATE` first?
- Could you change the Design Parameters to `area`, `aspectRatio`, `taperRatio`, `sweep`, and `twist`?

$$AR = \frac{b^2}{S} \qquad S = b(c_{\text{tip}} + c_{\text{root}})/2 \qquad \tau = \frac{c_{\text{tip}}}{c_{\text{root}}}$$

Simple Fuselage (1)

- Fuselage by blending a series of super-ellipses (SUPELLs), where the dimensions of the X-sections are provided in arrays



Simple Fuselage (2)

xloc	width	zcent	height	power
0.0	0.0	0.0	0.0	2
1.0	1.0	0.1	1.0	2
4.0	1.6	0.4	2.0	3
8.0	1.6	0.4	2.0	3
12.0	1.0	0.3	1.2	2
16.0	0.8	0.2	0.4	2

Simple Fuselage (3)

- Can you make the radius at the nose 0.2 in a top view and 0.1 in a side view?
- Can you make the fuselage between the two sections whose power is 3 have a constant cross-section?
- Can you create a SheetBody that has a plane of symmetry and cross-sections at every y, starting at $y = 1/2$ and spaced with $\Delta y = 1$?
- Can you color the odd-numbered bulkheads red and even-numbered bulkheads blue?
- Can you color the Edges at the intersections of the symmetry plane and bulkheads white?

Simple Fuselage (4)