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SUPEROPT Project and Sense Constraints

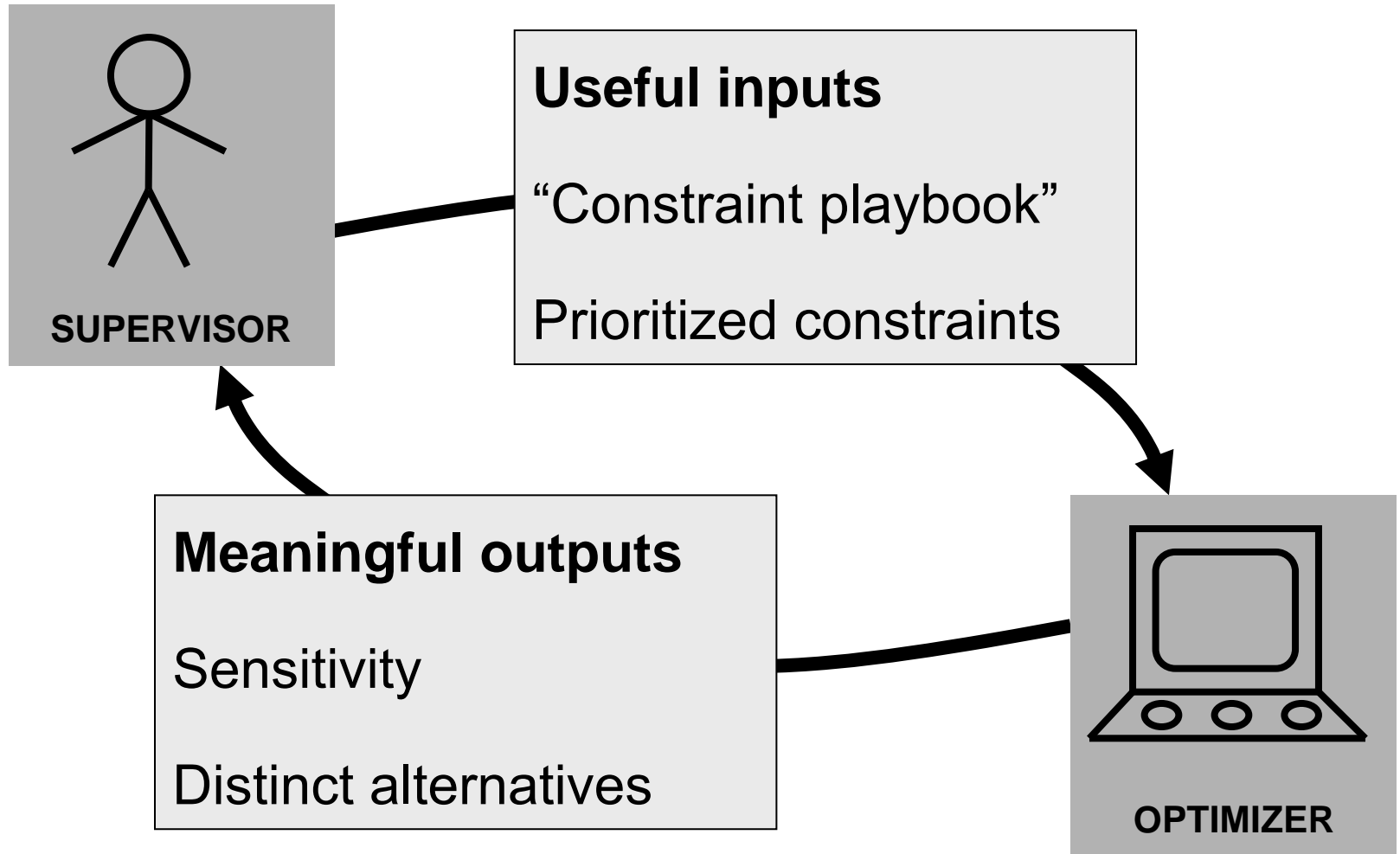
SESAR Innovation Days, Toulouse, Nov/Dec 2011



The Project

- ***SUPEROPT*** – Supervision of Route Optimizers
- Find trajectory optimizers that are suitable for human interaction
 - Selecting and applying optimizers
 - ***Not*** developing new ones or HMI

The Project

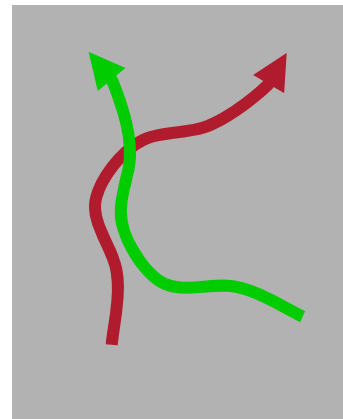
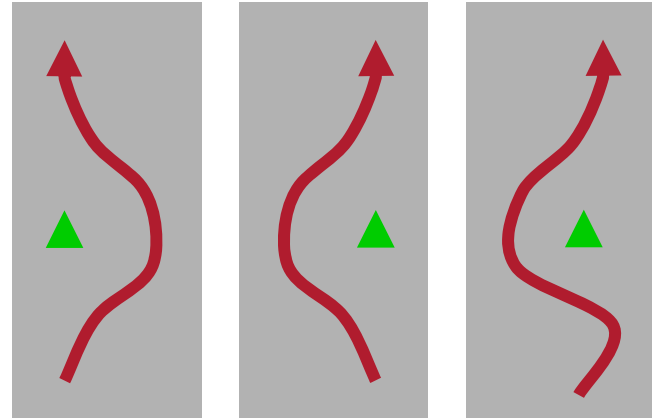


So Far

- Main body of work just about to start
- Today: initial results
 - Constraining the sense of a conflict resolution
- Who is the supervisor?
 - Big question: for now, executive controller

Constraining the Sense

- Tricky to formulate
- Constraint: integrated angular change ≥ 0
 - Or < 0 for opposite
- Angle change robustly captures the sense
 - Independent of direction or aircraft ordering



MILP Separation Constraints

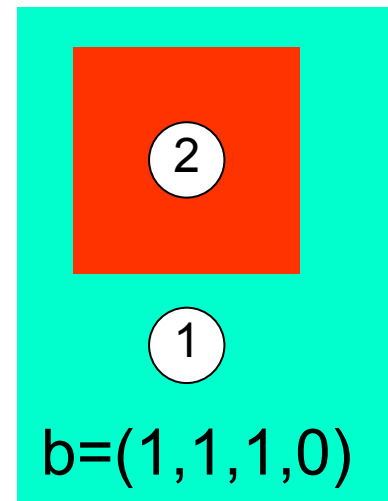
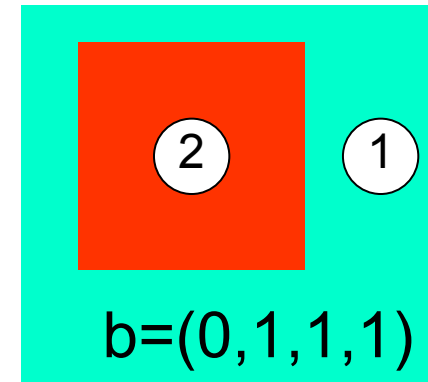
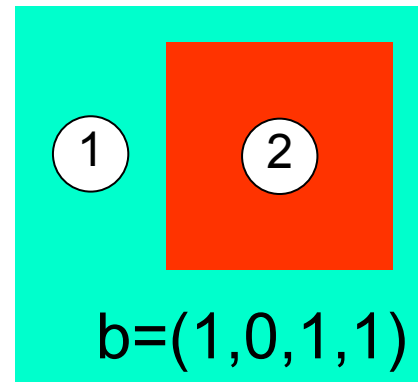
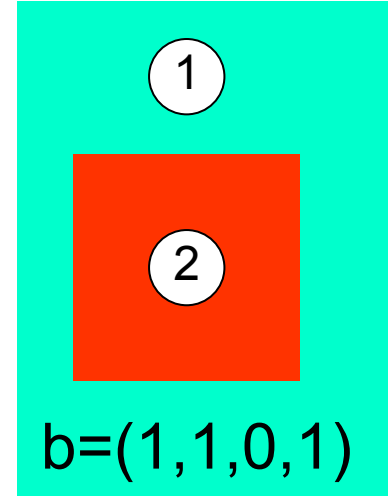
$$x_1 - x_2 \geq R - Mb_1$$

and $x_2 - x_1 \geq R - Mb_2$

and $y_1 - y_2 \geq R - Mb_3$

and $y_2 - y_1 \geq R - Mb_4$

and $\sum_{k=1}^4 b_k = 3$



MILP Separation Constraints

$$x_1 - x_2 \geq R - Mb_1$$

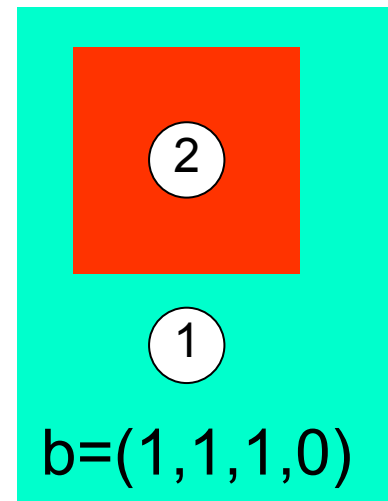
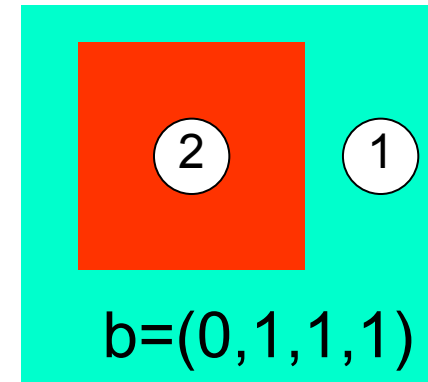
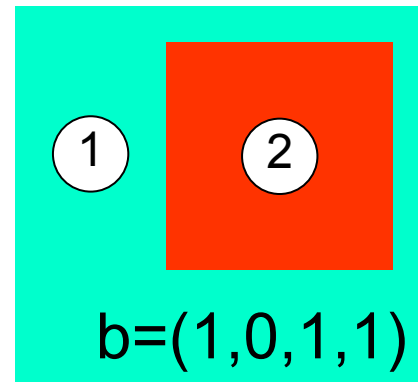
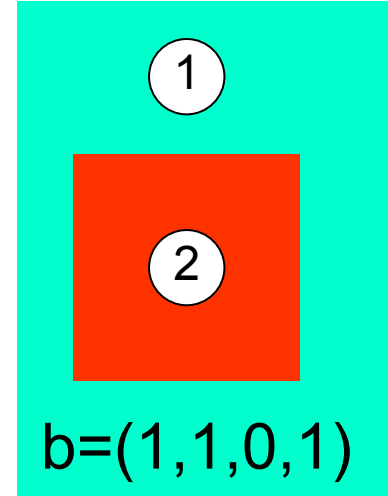
$$\text{and } x_2 - x_1 \geq R - Mb_2$$

$$\text{and } y_1 - y_2 \geq R - Mb_3$$

$$\text{and } y_2 - y_1 \geq R - Mb_4$$

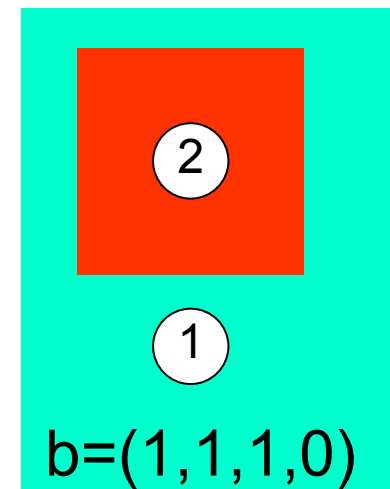
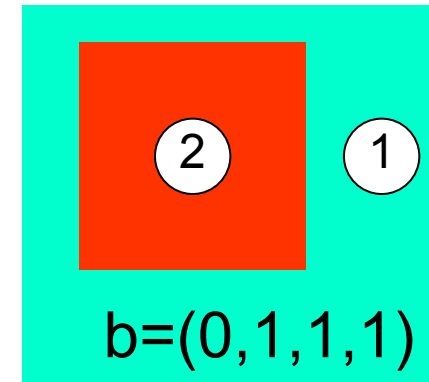
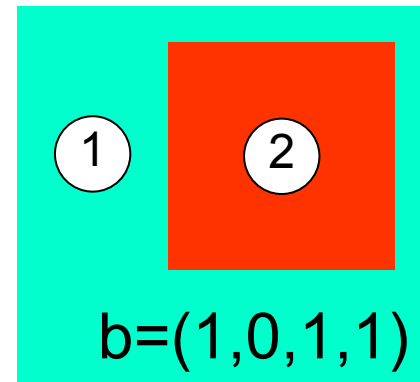
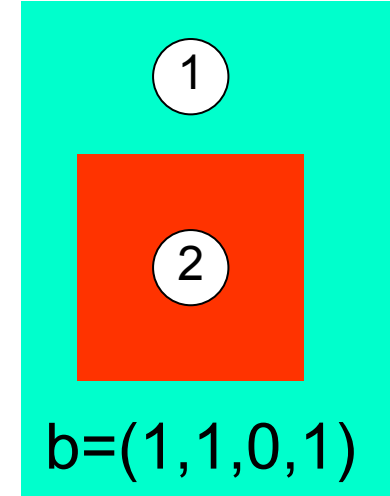
$$\text{and } \sum_{k=1}^4 b_k = 3$$

Sense can be related to the sequence of binary settings



MILP Sense Constraints

- New binary decision variables
 - $m_{CW}(i,k)=1$ if move is clockwise from quadrant i at time k
 - $m_{ACW}(i,k)=1$ if move is anticlockwise from quadrant i at time k
 - $m_{NR}(i,k)=1$ if no move from quadrant i at time k
- Choice of m fixes b

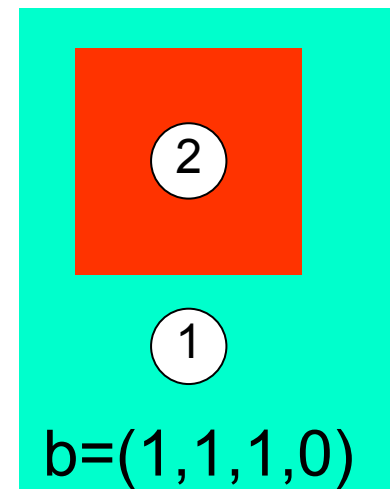
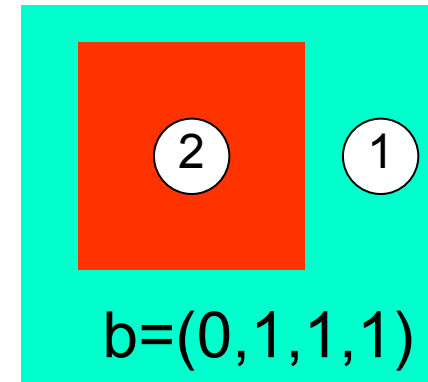
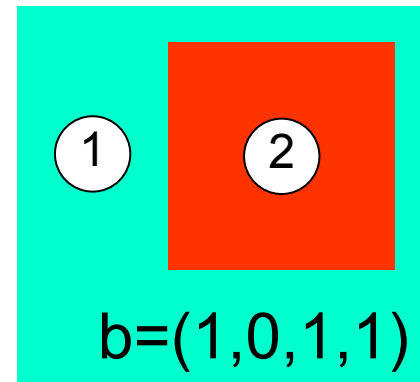
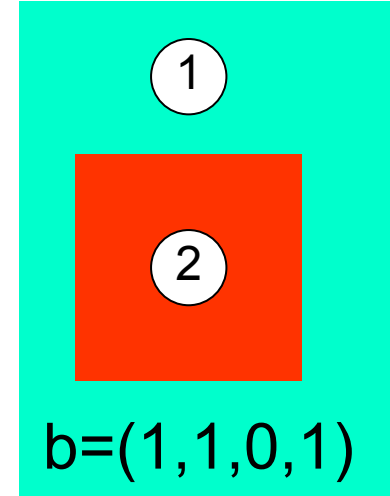


MILP Sense Constraints

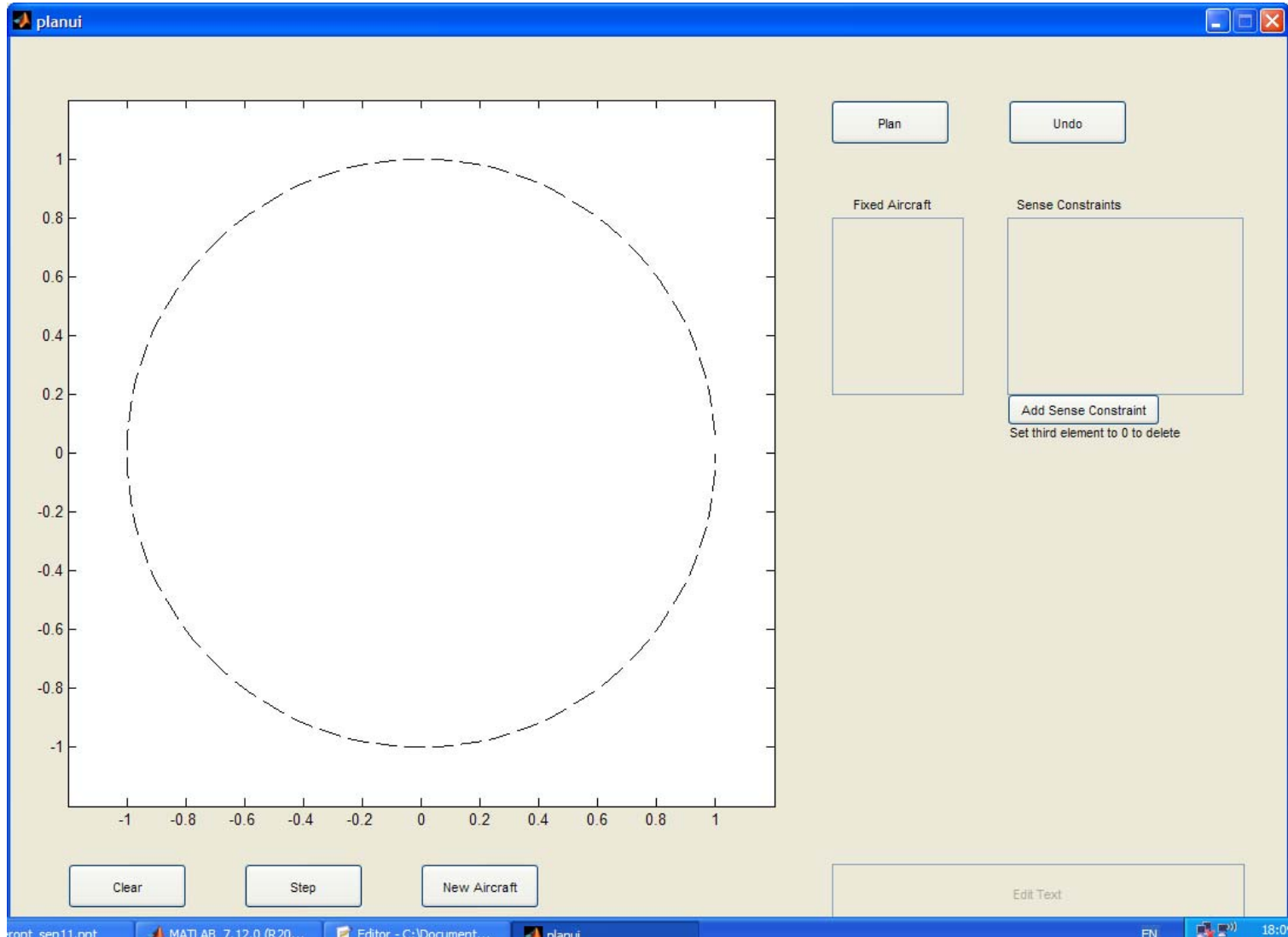
- For clockwise resolution, number of clockwise moves $>$ number of anticlockwise moves

$$\sum m_{CW} > \sum m_{ACW}$$

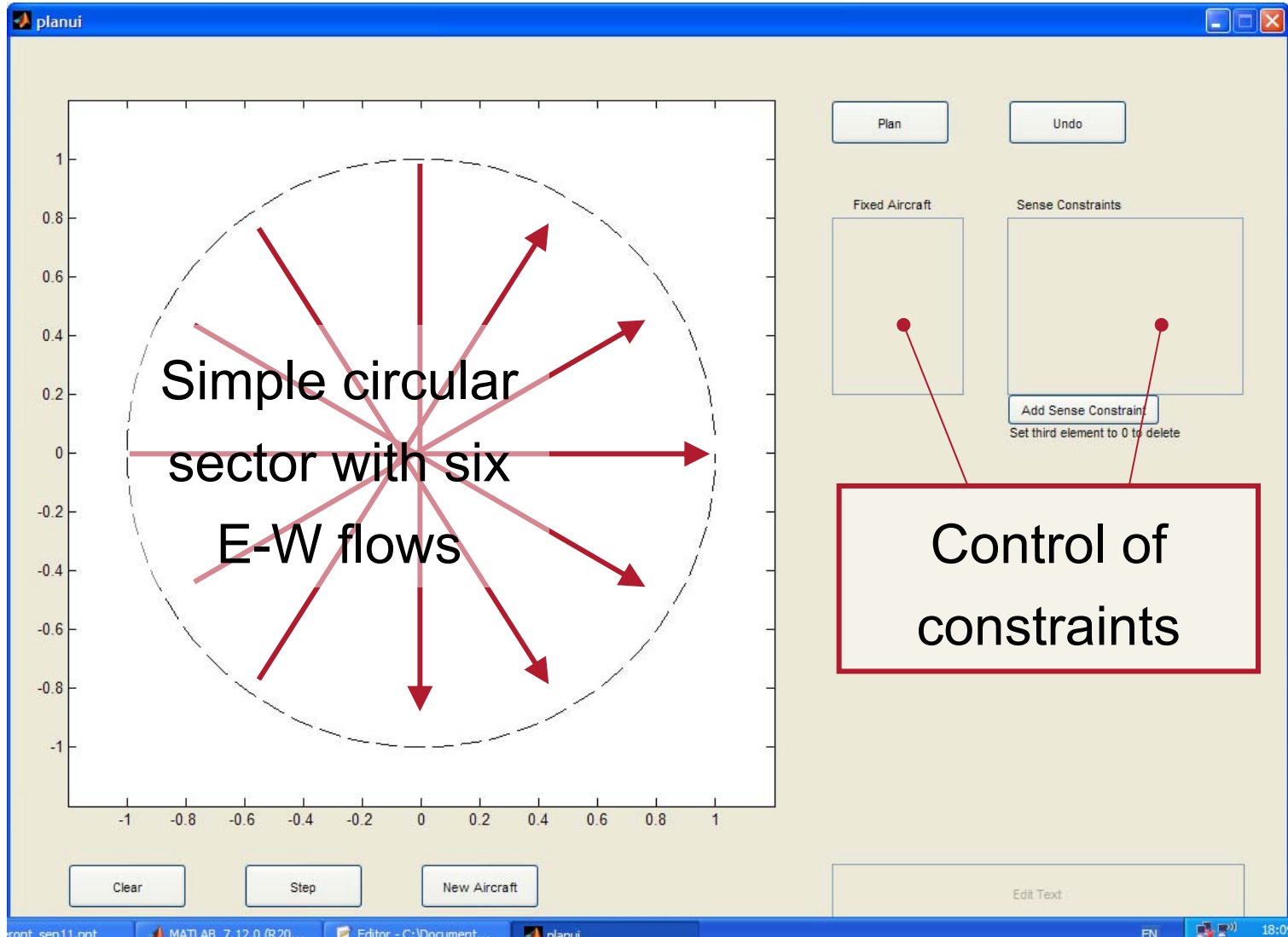
- Vice versa for anticlockwise

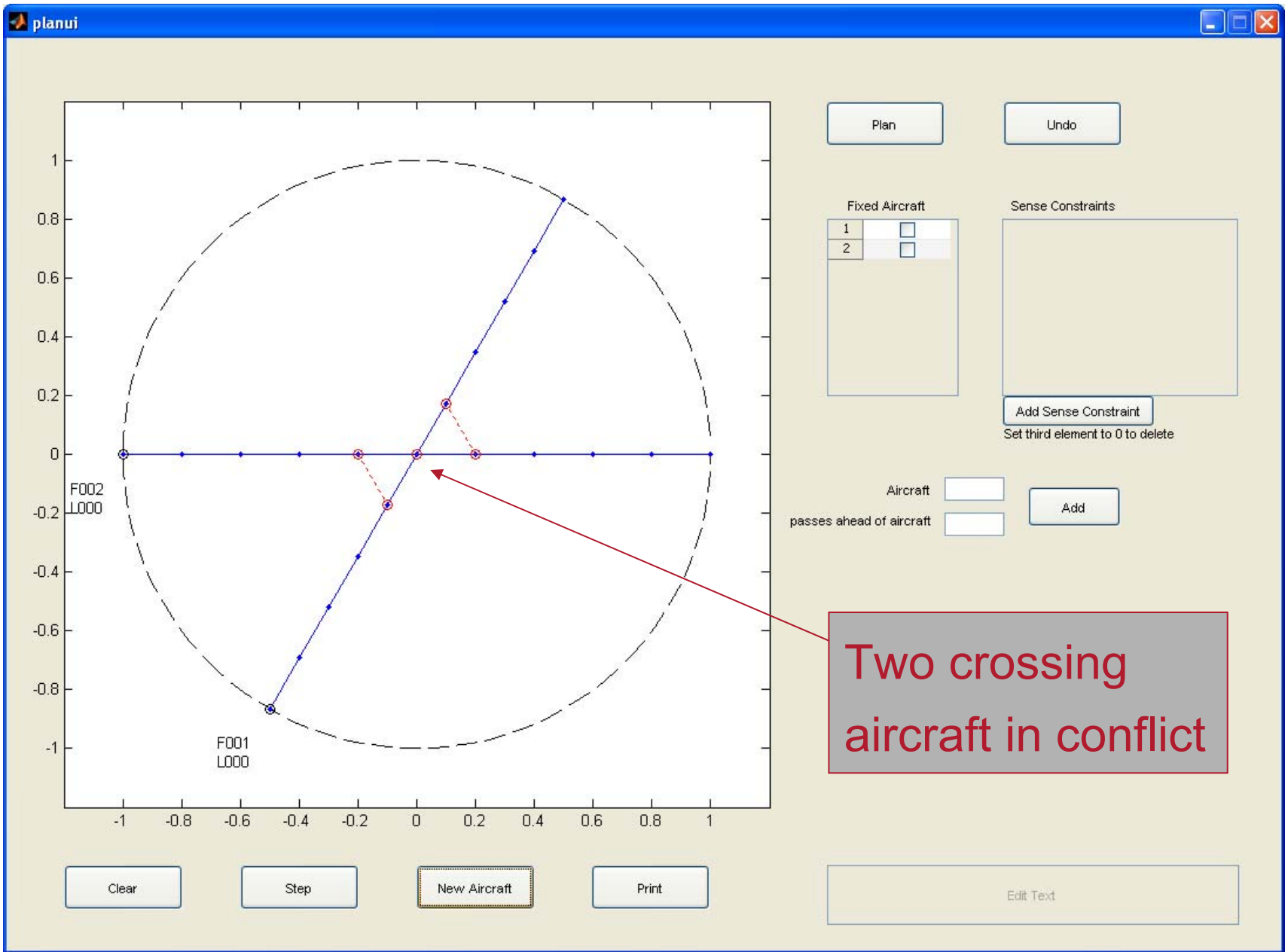


Demonstration



Demonstration





Two crossing aircraft in conflict

The screenshot shows the 'planui' software interface. On the left is a 2D plot with axes from -1 to 1. A dashed circle is centered at (0,0) with a radius of 1. Two aircraft paths are shown: 'F001 L000' (a blue line with dots) and 'F002 L000' (a blue line with dots). The paths cross near the origin. On the right, there are control panels. The 'Fixed Aircraft' panel has a table with two rows and two columns. The 'Sense Constraints' panel has a table with three columns and one row. A red arrow points from the 'Add Sense Constraint' button to the cell containing '1' in the 'Sense Constraints' table. Below the 'Add Sense Constraint' button is the text 'Set third element to 0 to delete'. At the bottom right, a status bar shows 'Solved in 2.674748 seconds'. At the bottom center, there are buttons for 'Clear', 'Step', 'New Aircraft', and 'Print'. At the bottom left, there are input fields for 'Aircraft' and 'passes ahead of aircraft' with an 'Add' button.

1	<input type="checkbox"/>
2	<input type="checkbox"/>

	1	2	3
1	2	1	-1

Resolve anti-clockwise

Solved in 2.674748 seconds

planui

Plan

Undo

Fixed Aircraft

1	<input type="checkbox"/>
2	<input type="checkbox"/>

Sense Constraints

	1	2	3
1	2	1	-1

Add Sense Constraint

Set third element to 0 to delete

Aircraft

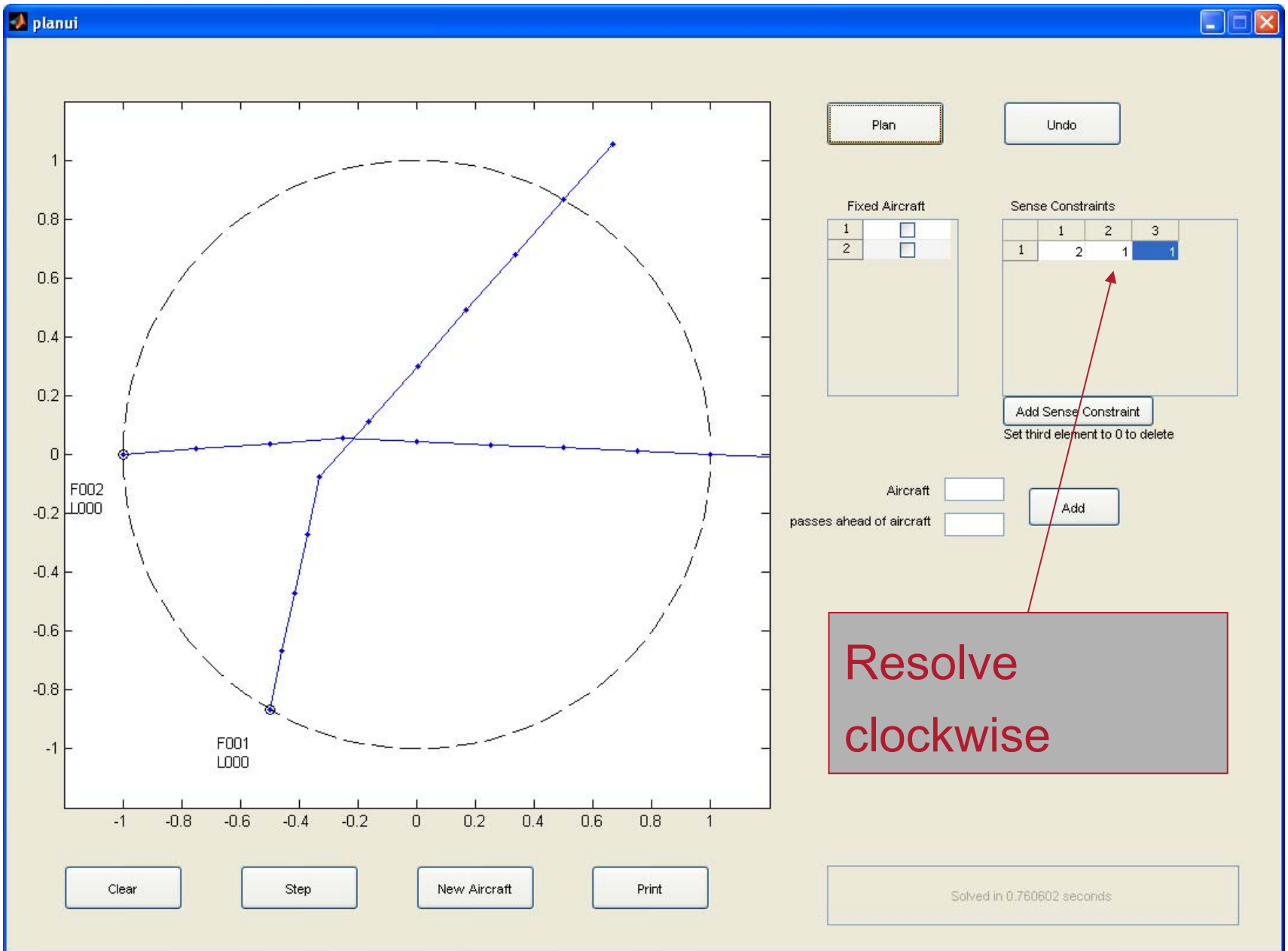
passes ahead of aircraft

Add

Resolve anti-clockwise

Clear Step New Aircraft Print

Solved in 2.674748 seconds



Resolve clockwise

planui

Plan Undo

Fixed Aircraft

1	<input type="checkbox"/>
2	<input type="checkbox"/>

Sense Constraints

	1	2	3
1	2	1	1

Add Sense Constraint
Set third element to 0 to delete

Aircraft
passes ahead of aircraft Add

Resolve clockwise

Clear Step New Aircraft Print

Solved in 0.760602 seconds

Three Aircraft

17

planui

Plan Undo

Fixed Aircraft

1	<input type="checkbox"/>
2	<input type="checkbox"/>
3	<input type="checkbox"/>

Sense Constraints

	1	2	3
1	2	1	-1
2	3	1	-1
3	3	2	-1

Add Sense Constraint
Set third element to 0 to delete

Aircraft
passes ahead of aircraft

FO01
LO00

FO02
LO00

FO03
LO00

Clear Step New Aircraft Print

Solved in 0.363414 seconds

Three Aircraft

18

planui

Plan Undo

Fixed Aircraft

1	<input type="checkbox"/>
2	<input type="checkbox"/>
3	<input type="checkbox"/>

Sense Constraints

	1	2	3
1	2	1	-1
2	3	1	-1
3	3	2	-1

Add Sense Constraint
Set third element to 0 to delete

Aircraft
passes ahead of aircraft

FO01
LO00

FO02
LO00

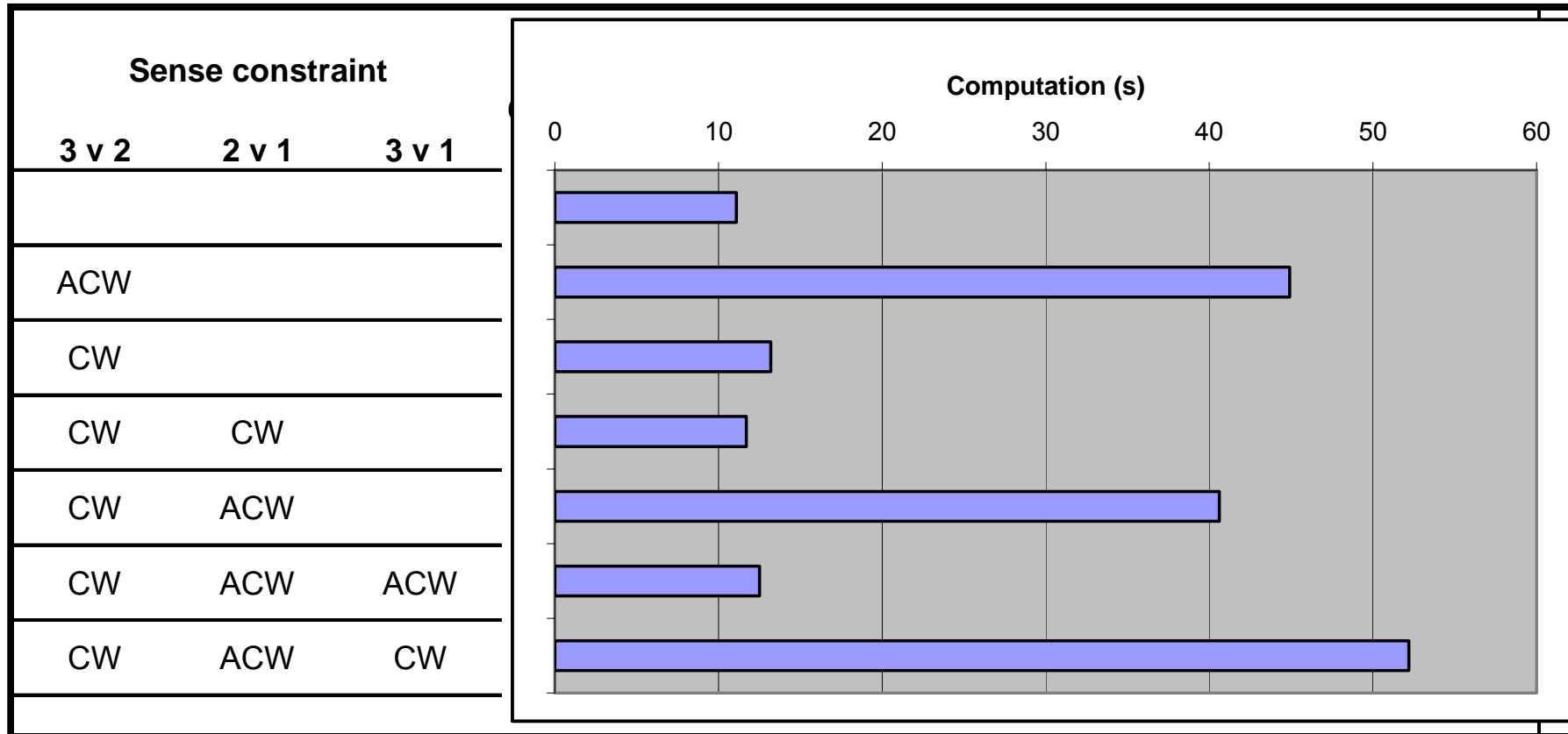
FO03
LO00

Clear Step New Aircraft Print

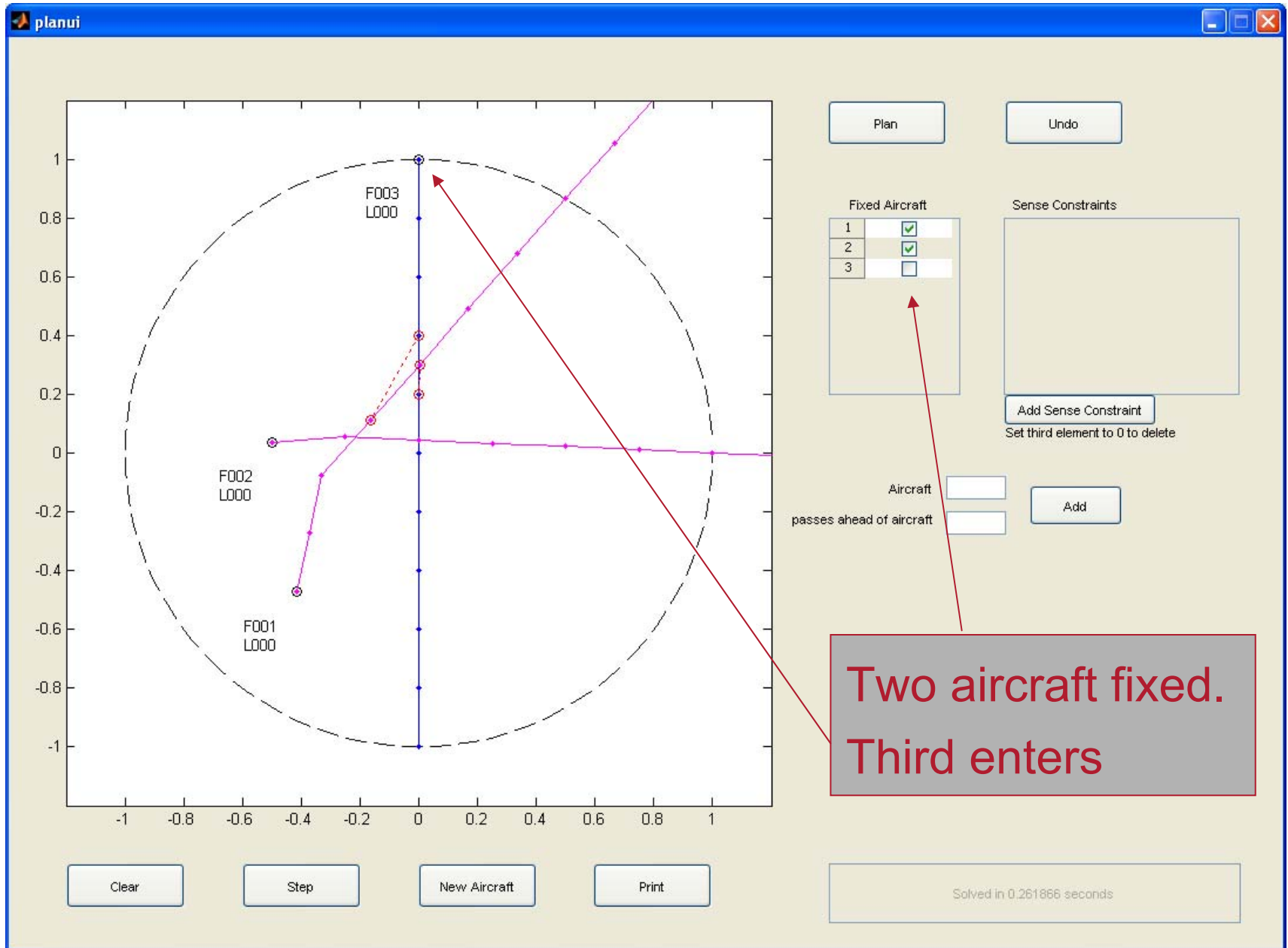
Solved in 35.560889 seconds

Resolve all 3 pairs
anticlockwise

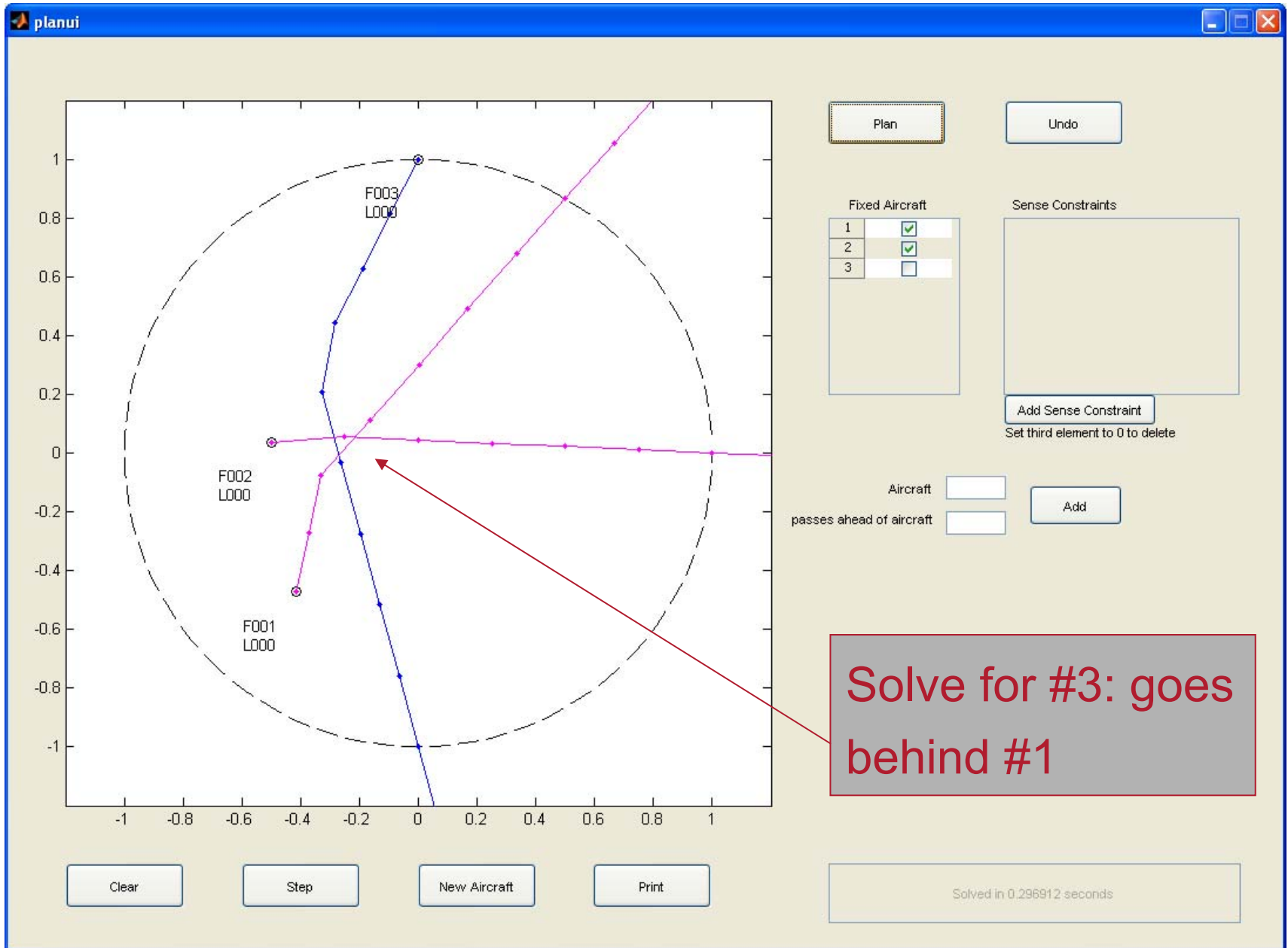
Computation



Ahead or Behind

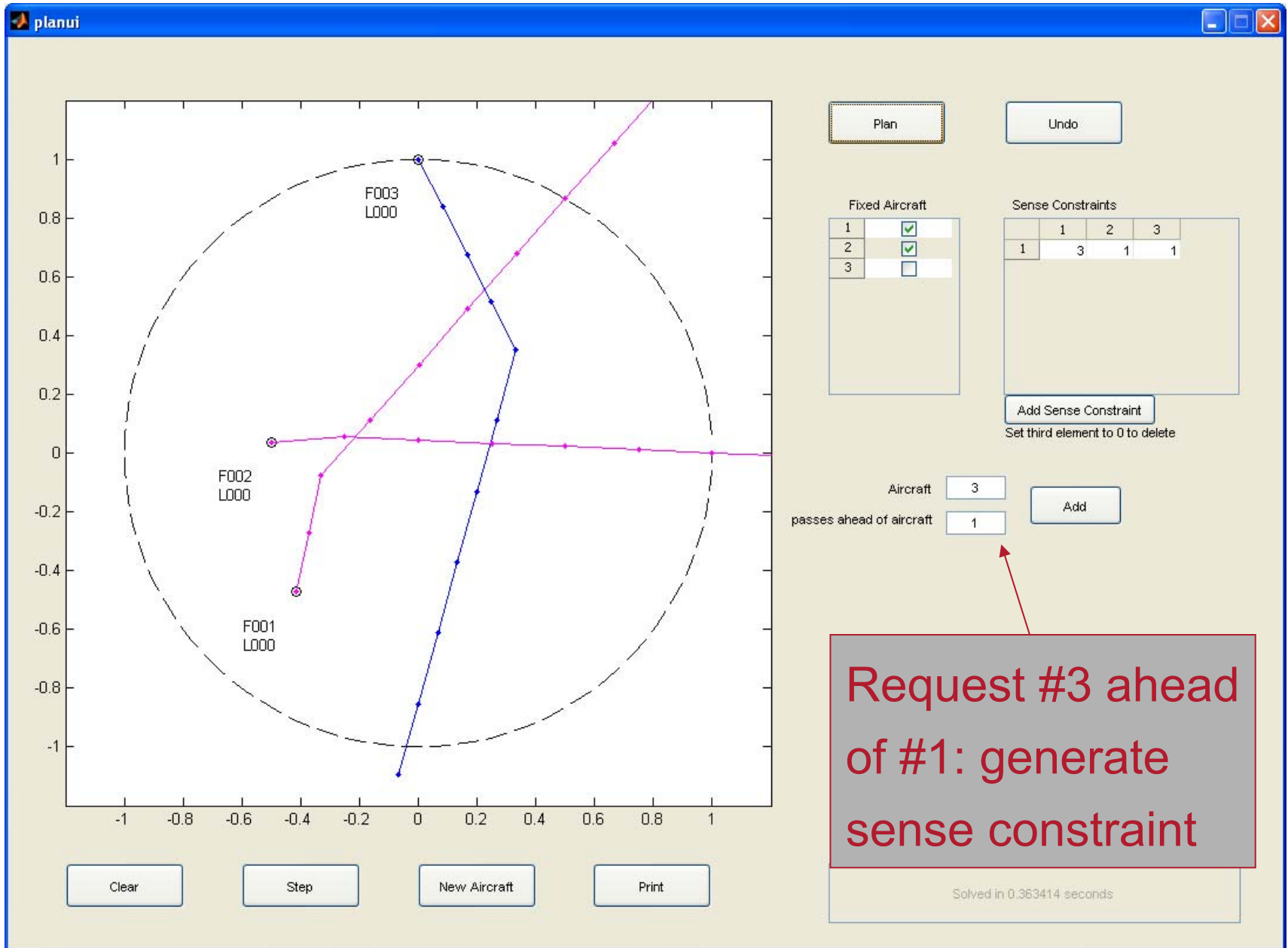


Ahead or Behind



Solve for #3: goes behind #1

Ahead or Behind

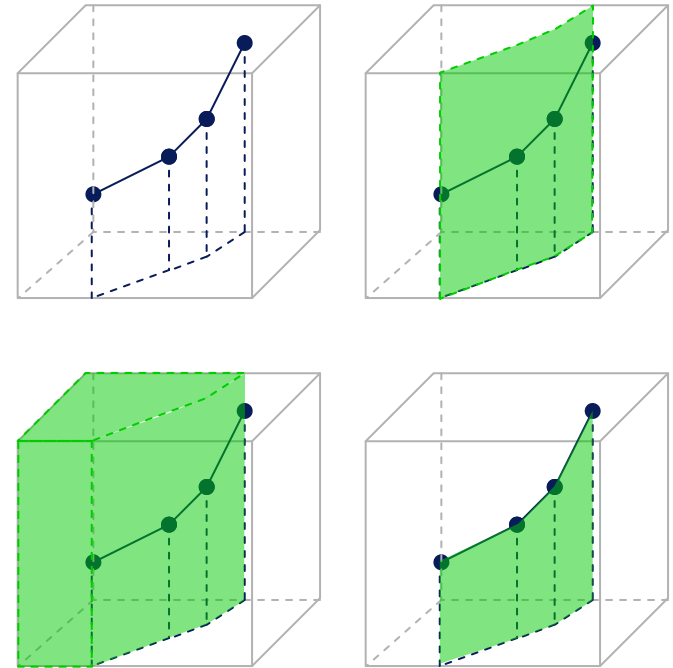


Summary

- Expressed sense constraints in terms of total angle change between aircraft
- Captured and constrained sense within MILP optimization
- Offers an intuitive control of conflict resolution optimization

Next Steps (1 of 2)

- More constraint trials
 - Corridor relative to nominal
 - Deviation from nominal
- Jump to 3-D
 - Easily done in the code
 - Expand possibilities for constraints
 - Resolve above/below
 - Deviate above/below



Next Steps (2 of 2)

- Switch to alternative nonlinear optimizer
 - Core methods available and understood
 - Incorporate new constraint forms
 - Compare with MILP
- Move on to prioritization
 - New idea for cost weight generation
 - Easily done in MILP
 - B&B idea for generic inclusion in any opt.