Effect of the Wind on the Potential Success of Executing a Teardrop Turnback Maneuver

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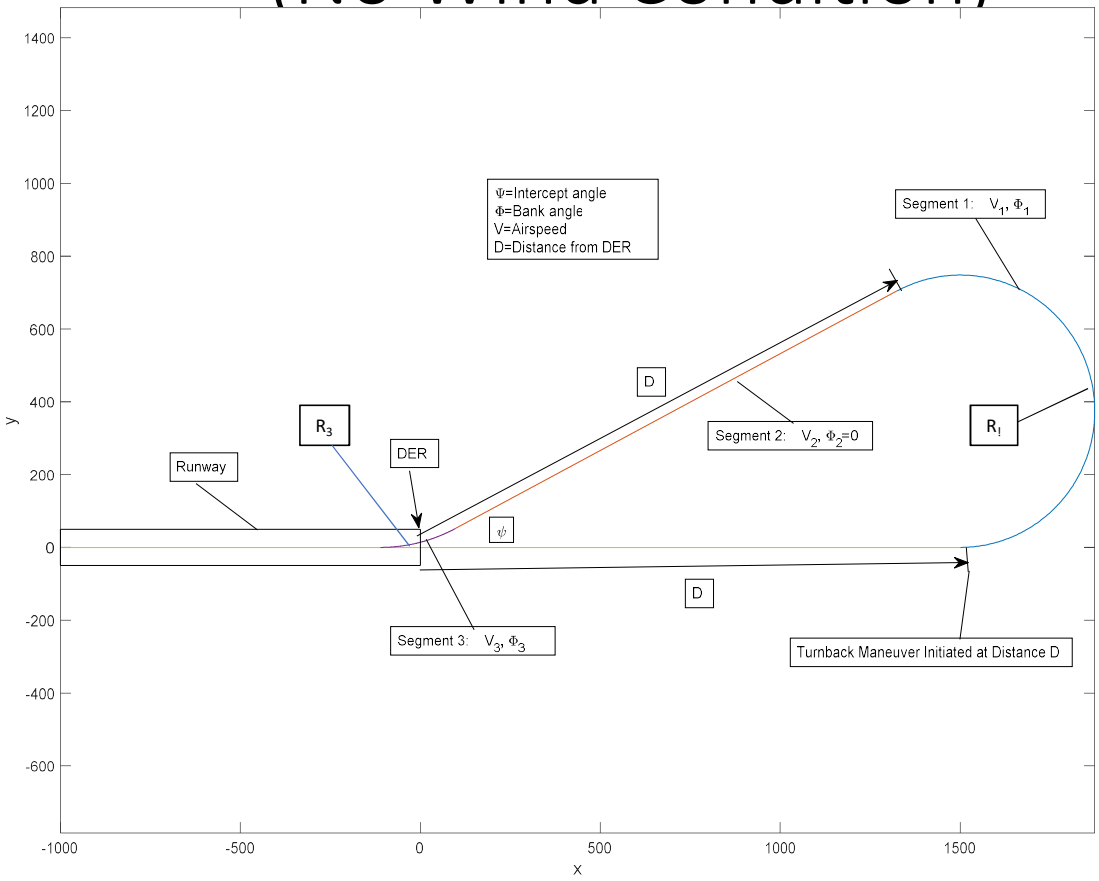
Segments of the Turnback Maneuver (No Wind Condition)



Simulation Parameters

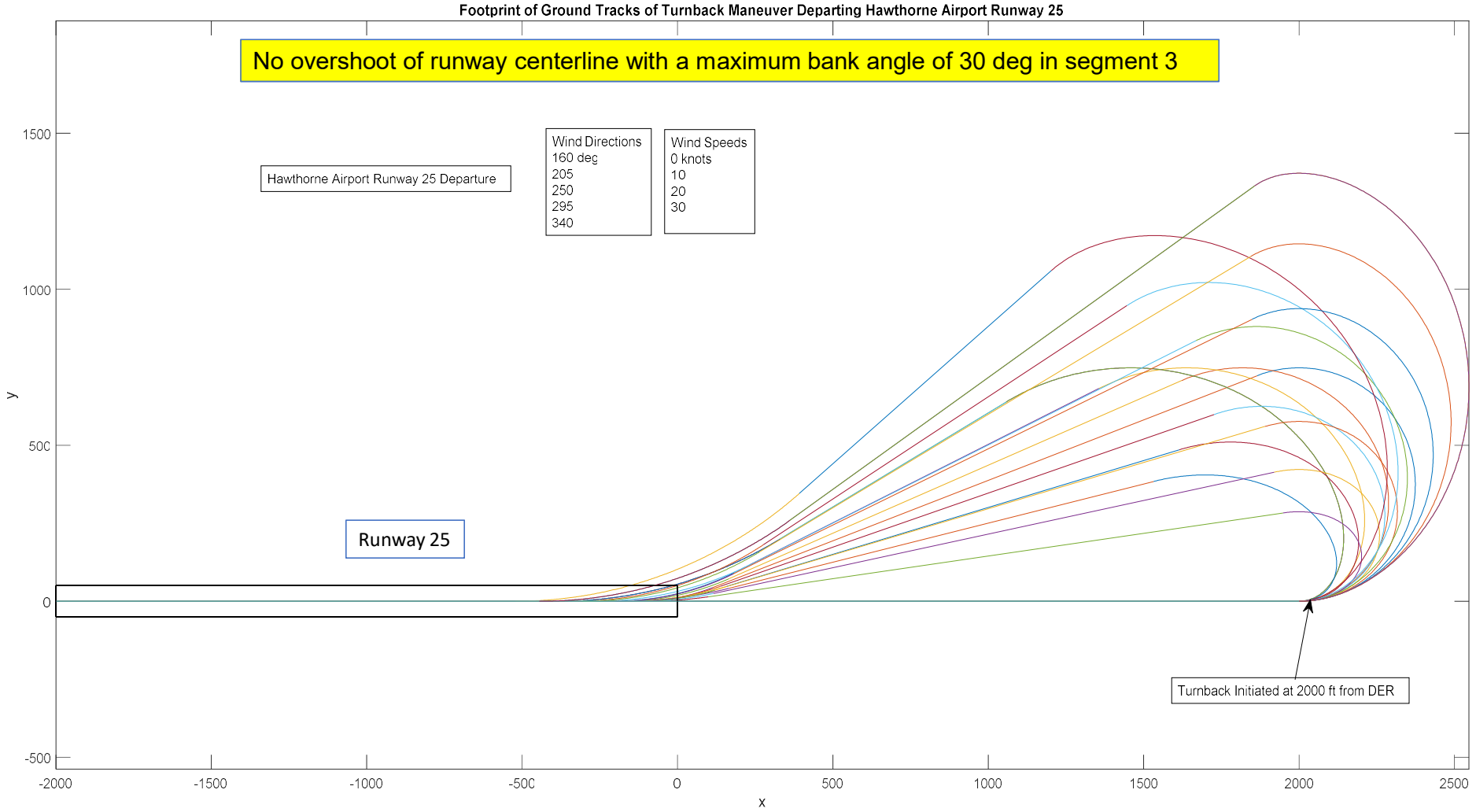
- Aircraft C-172
  - Weight 2300 lbs
  - Sea level density
- Departure runway 25
- Segment 1 flown at V_1=65 KCAS with 45 deg bank angle
- Segment 2 flown at V_2=65 KCAS wings level (best glide speed)
- Segment 3 flown at V_3=65 KCAS with maximum bank angle of 30 deg
- Wind speeds: 0, 10, 20 and 30 knots
- Wind directions: 160, 205, 250, 295, and 340 deg
- Turnback initiated at 1000 and 2000 feet from the DER

Simulation Parameters (Cont.)

- Assume the option of a right turn is not allowed due to terrain
  - Under this assumption the aircraft will be turning away from the wind when the wind is coming from the right side while departing runway 25
- Aerodynamic parameters
  - Wings level best glide speed 65 KCAS
    - Max L/D=9.09
      - Glide path angle relative to the air mass 6.28 deg
    - Parasite drag coefficient 0.0506
    - Induced drag value of k= 0.0597
  - Bank angle in segment 1: 45 degrees
    - Altitude loss per degree of turn: 1.063 feet/deg
  - Bank angle in segment 3: Limited to a maximum of 30 degrees
    - Altitude loss per degree of turn: 3.06 feet/deg based on bank angle at crosswind point during turn around a point
      - Crosswind bank angle depends on TAS, maximum bank angle and wind speed ratio

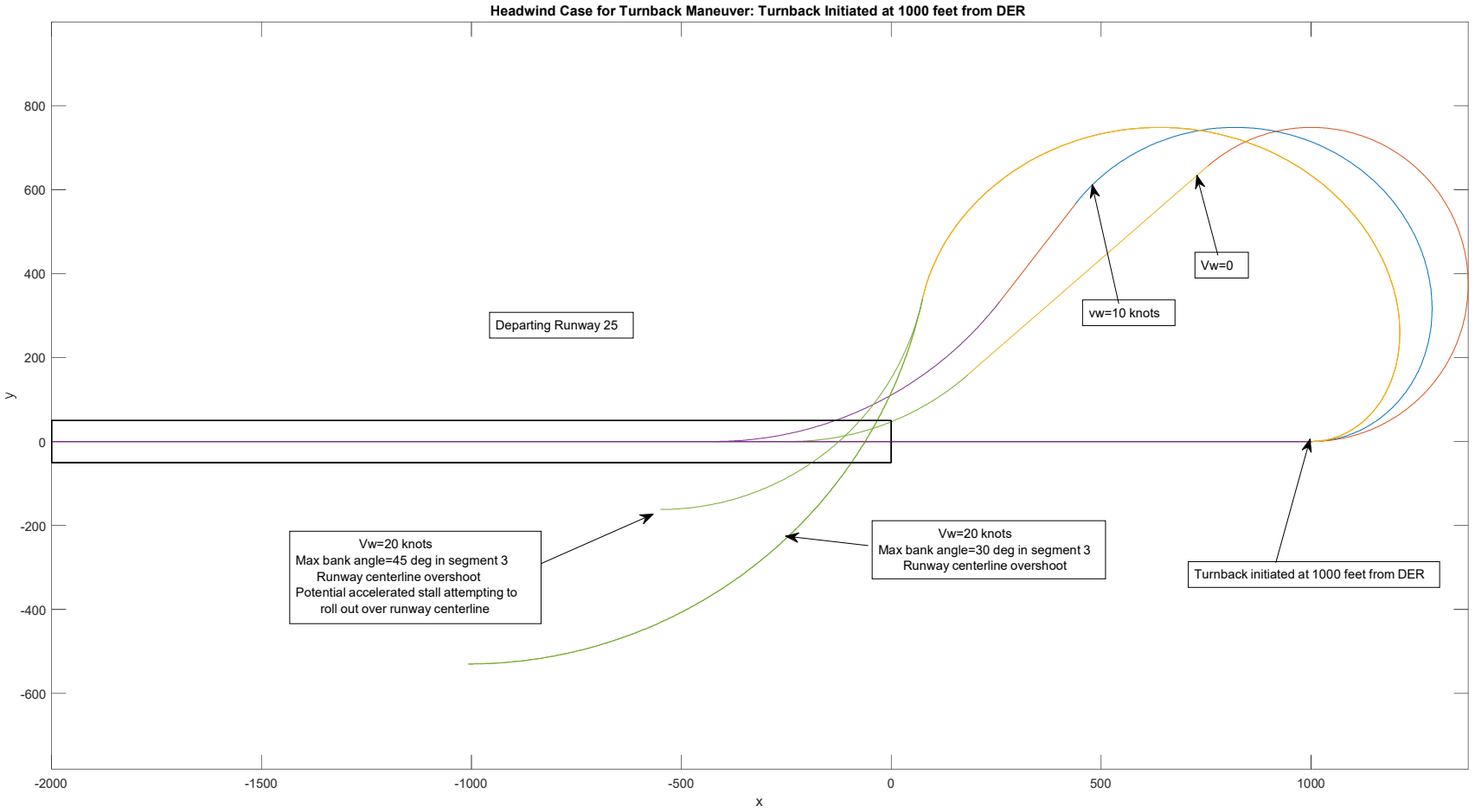
Objective

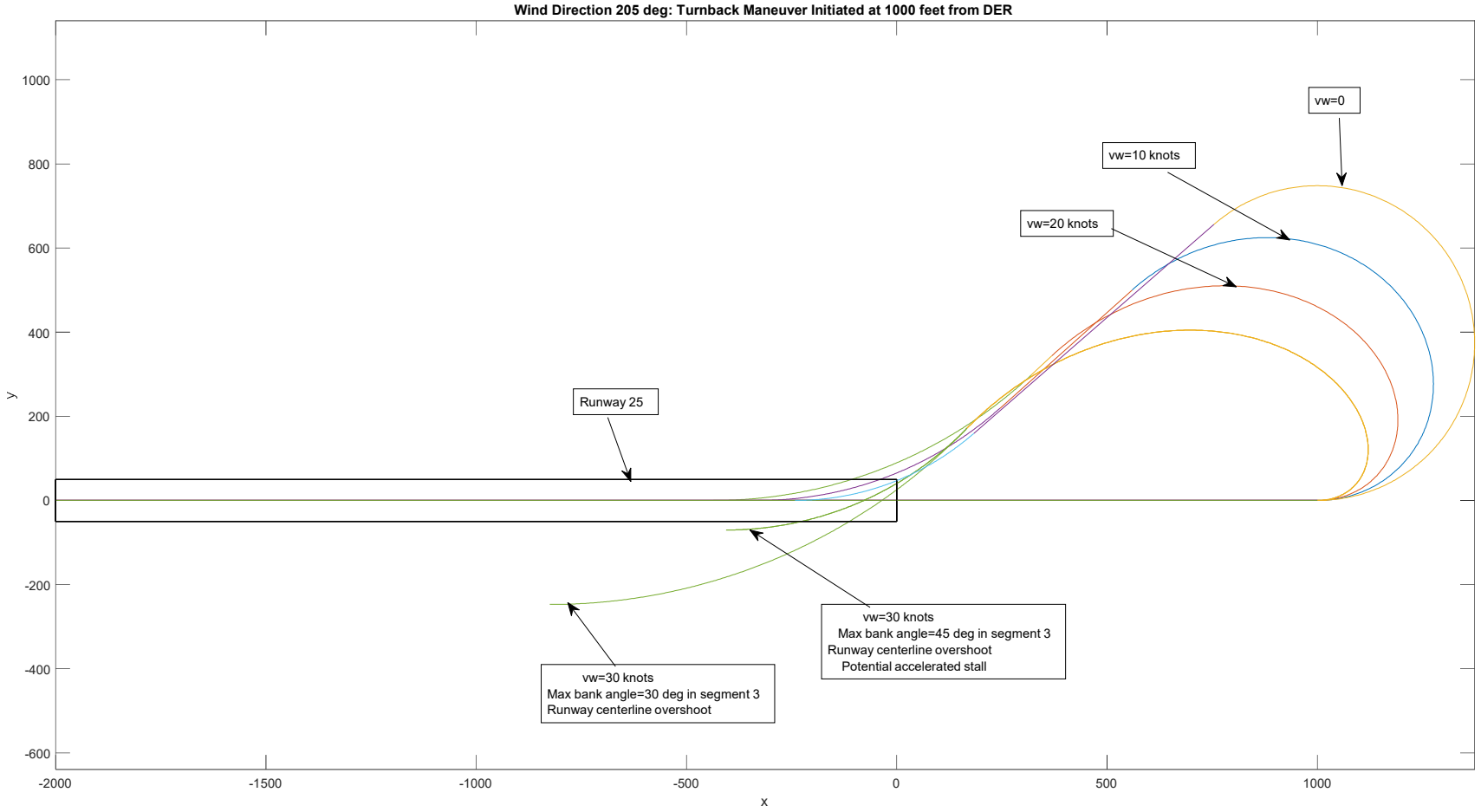
- Turnback maneuver initiated at 1000 and 2000 feet from DER
  - Determine the ground track footprint of the turnback maneuver
  - Determine the total altitude loss in the turnback maneuver as function of wind speed and direction

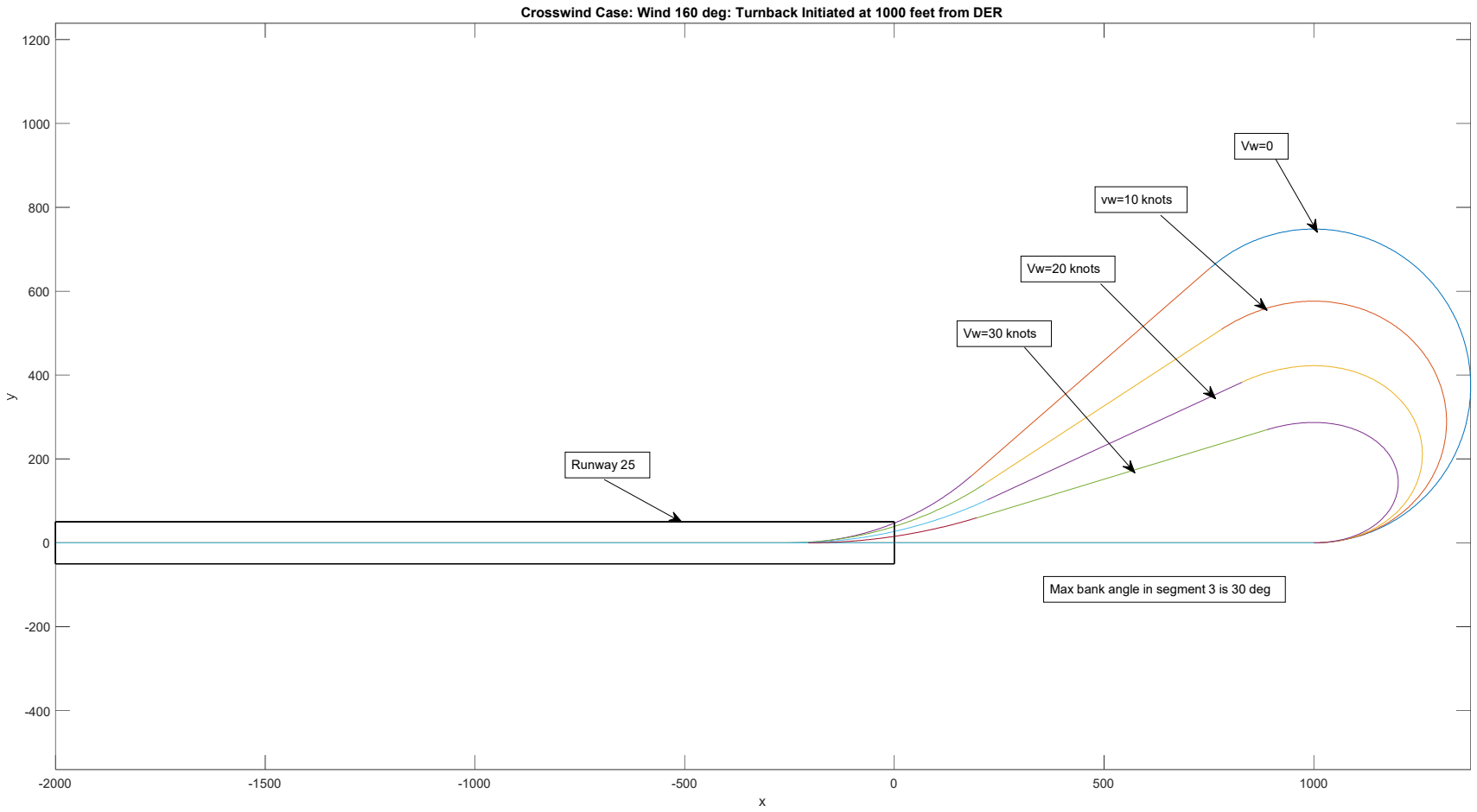

Footprint of Ground Tracks of Turnback Maneuver Departing Hawthorne Airport Runway 25
No overshoot of runway centerline with a maximum bank angle of 30 deg in segment 3
Hawthorne Airport Runway 25 Departure
Wind Directions
160 deg
205
250
295
340
Wind Speeds
0 knots
10
20
30
Runway 25
Turnback Initiated at 2000 ft from DER
1500
1000
500
0
-500
y
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
x

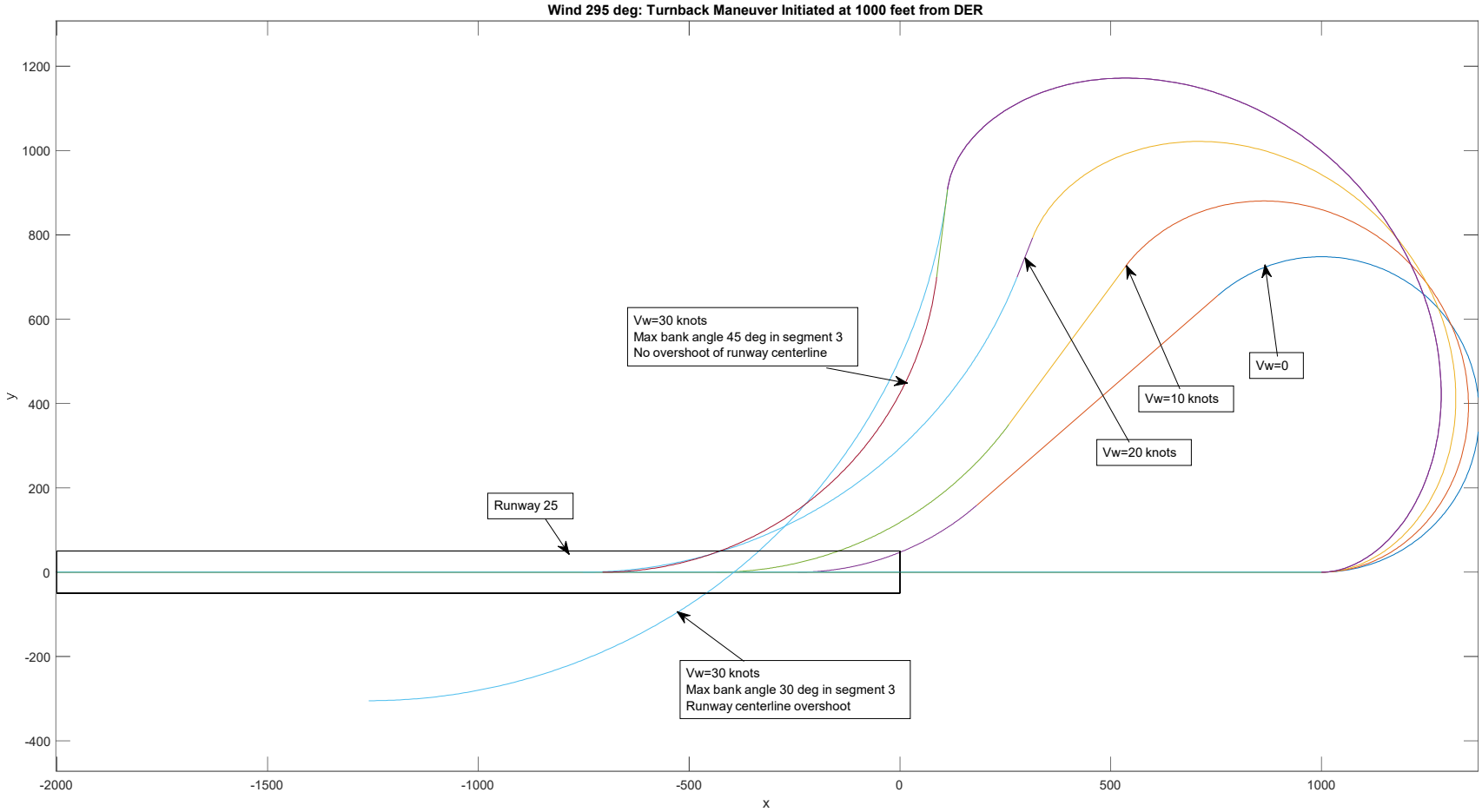
Departure Runway 25: Turnback Initiated at 2000 feet from DER
C-172 at Gross Weight (2300 lbs) at Sea Level Density

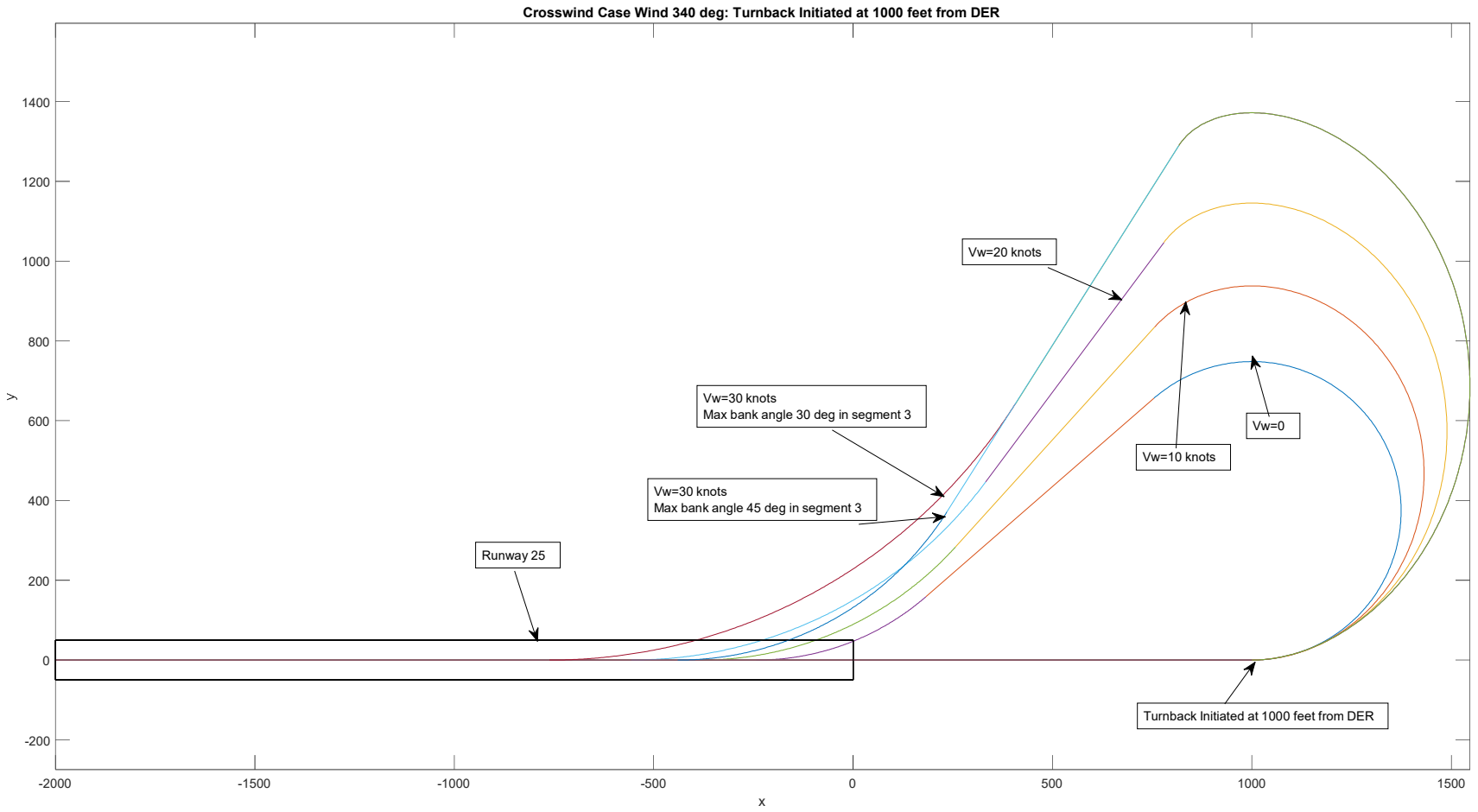
Wind Speed	Wind Direction	Alt Loss Seg-1	Alt Loss Seg-2	Alt Loss Seg-3	Total Alt Loss
0	250	214	207	30	451
10	250	220	153	49	422
20	250	228	109	81	418
30	250	239	68	137	444
10	205	201	163	39	403
20	205	187	133	49	369
30	205	171	113	59	343
10	160	190	197	31	418
20	160	167	199	54	420
30	160	142	215	142	499
10	295	235	176	52	463
20	295	259	151	89	499
30	295	285	130	152	567
10	340	237	222	47	506
20	340	259	252	66	577
30	340	282	309	92	683


Headwind Case for Turnback Maneuver: Turnback Initiated at 1000 feet from DER
Departing Runway 25
Vw=0
vw=10 knots
Vw=20 knots
Max bank angle=45 deg in segment 3
Runway centerline overshoot
Potential accelerated stall attempting to
roll out over runway centerline
Vw=20 knots
Max bank angle=30 deg in segment 3
Runway centerline overshoot
Turnback initiated at 1000 feet from DER
800
600
400
200
0
-200
-400
-600
y
-2000
-1500
-1000
-500
0
500
1000
x


Wind Direction 205 deg: Turnback Maneuver Initiated at 1000 feet from DER
vw=0
vw=10 knots
vw=20 knots
Runway 25
vw=30 knots
Max bank angle=45 deg in segment 3
Runway centerline overshoot
Potential accelerated stall
vw=30 knots
Max bank angle=30 deg in segment 3
Runway centerline overshoot
y
x
1000
800
600
400
200
0
-200
-400
-600
-2000
-1500
-1000
-500
0
500
1000


Crosswind Case: Wind 160 deg: Turnback Initiated at 1000 feet from DER
Vw=0
vw=10 knots
Vw=20 knots
Vw=30 knots
Runway 25
Max bank angle in segment 3 is 30 deg
y
x
1200
1000
800
600
400
200
0
-200
-400
-2000
-1500
-1000
-500
0
500
1000


Wind 295 deg: Turnback Maneuver Initiated at 1000 feet from DER
Vw=30 knots
Max bank angle 45 deg in segment 3
No overshoot of runway centerline
Vw=10 knots
Vw=0
Vw=20 knots
Runway 25
Vw=30 knots
Max bank angle 30 deg in segment 3
Runway centerline overshoot
y
x
1200
1000
800
600
400
200
0
-200
-400
-2000
-1500
-1000
-500
0
500
1000


Crosswind Case Wind 340 deg: Turnback Initiated at 1000 feet from DER
Vw=20 knots
Vw=30 knots
Max bank angle 30 deg in segment 3
Vw=30 knots
Max bank angle 45 deg in segment 3
Runway 25
Vw=10 knots
Vw=0
Turnback Initiated at 1000 feet from DER
y
x
1400
1200
1000
800
600
400
200
0
-200
-2000
-1500
-1000
-500
0
500
1000
1500

Departure Runway 25: Turnback Initiated at 1000 feet from DER
C-172 at Gross Weight (2300 lbs) at Sea Level Density

Wind Speed	Wind Direction	Alt Loss Seg 1	Alt Loss Seg 2	Alt Loss Seg 3	Total Alt Loss
0	250	235	83	59	377
10	250	254	30	108	392
20	250	292	0	222	514
20 (45 deg)	250	292	0	140	432
30	250	No Segment 2 Modified Turnback	No Segment 2 Modified Turnback	No Segment 2 Modified Turnback	No Segment 2 Modified Turnback
10	205	229	40	86	355
20	205	223	6	128	357
30	205	220	0	199	419
30 (45 deg)	205	220	0	122	342
10	160	209	69	63	341
20	160	181	68	62	311
30	160	152	77	112	341
10	295	264	53	102	419
20	295	295	13	168	476
30	295	322	0	261	583
30 (45 deg)	295	322	36	159	517
10	340	258	93	82	433
20	340	278	112	107	497
30	340	297	147	136	580
30 (45 deg)	340	297	208	82	587

Conclusion

- We need to stop keying in on just how much altitude we need for a successful turnback maneuver and start talking about the resultant ground track during the maneuver when a wind is present
  - The exact ground track during the maneuver controls the total altitude loss
- The ground track of the aircraft during the turnback maneuver depends on
  - TAS
  - Wind speed ratio - V_{wind}/TAS
  - Wind direction relative to runway heading
  - Distance from the DER at which the turnback maneuver is initiated
- Altitude loss in segment 1 depends on the final heading while tracking directly to the DER
  - Final heading obtained from an exact analytic equation for the aircraft heading at the end of Segment 1
    - Obtained by determining what heading will equate the aircraft bearing to the DER with the aircraft track angle to the DER
      - Solution is a function of relative wind angle to departure runway, windspeed ratio, and initial distance from DER at which the turnback maneuver is initiated

Conclusions (Cont.)

- Altitude loss in segment 2 when tracking inbound directly to the DER depends glide path angle in segment 2
  - Glide path angle during the wings level glide in segment 2 depends on the ground speed and the glide path angle relative to the air mass when flying inbound toward the DER
    - Ground speed is a function of the TAS, inbound track angle, wind speed, and wind direction while flying inbound toward the DER
- Altitude loss in segment 3 depends on the aircraft heading in segment 2, the wind direction relative to the runway, and the bank angle
  - Bank angle is varying in the presence of a wind while flying segment 3
    - Segment 3 radius is patched to segment 2 uses exact mathematical solution of a turn around a point
      - Specifying maximum bank angle for the turn around a point, TAS, and the wind speed ratio provides the radius of the turn in segment 3 which smoothly patches in to segment 2

Conclusions (Cont.)

- Knowledge of the altitude loss during the turnback maneuver is necessary to determine the minimum required runway length for a potentially successful turnback maneuver
  - Altitude loss in turnback maneuver allows one to determine the required height over the DER as a function of distance from the DER at which the turnback is initiated
  - Given a takeoff and climb profile for the aircraft and the required height over the DER allows one to determine the required minimum runway length as a function of distance from the DER
  - Key is to determine both minimum and maximum distances from the DER for which a potentially successful turnback maneuver can be executed
    - Need to include issues with terrain, airport structures, etc.
    - Any wind condition exceeding maximum demonstrated crosswind component would be considered a no-go for takeoff
      - Example: 30 knot crosswind case would not need to be considered with a 15 knot maximum demonstrated crosswind component for the aircraft