# Briefing Contents

- Analysis assumptions
- Heat loads
- Cooling mass flow calculation
- Bay penetration sizing analysis
- M5 Flight Test Profile analysis

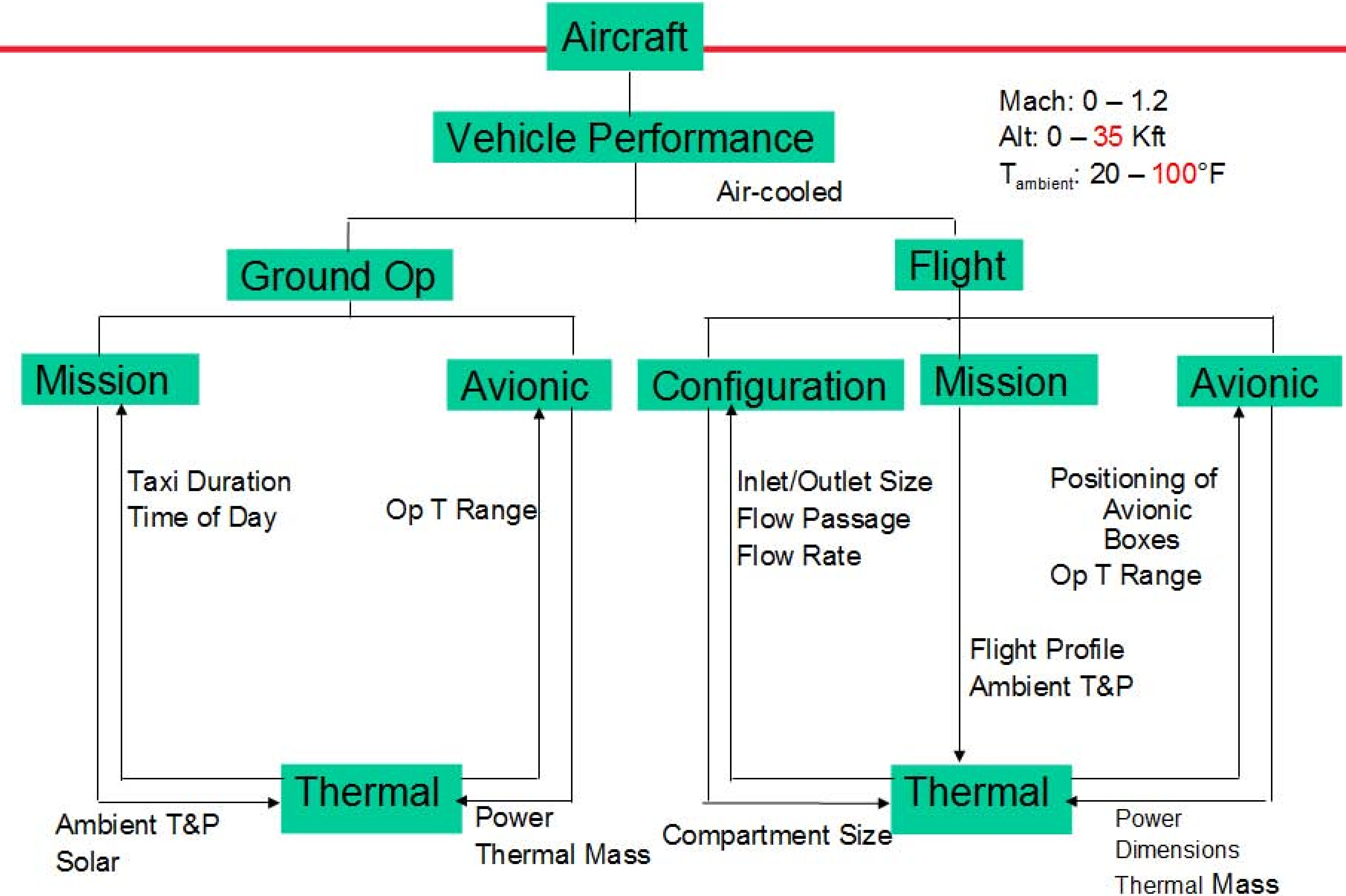
# Internal Cooling Analysis Assumptions

- Avionics will be air-cooled
- Rates of waste heat produced by Avionics are as specified in Master Equipment List
- AV has 2 inlets, 4 outlets for cooling air flow.
- AV will operate in Dryden weather (20° to 100°F ambient temperature)
- Altitude of operation is limited from sea level to 35 Kft.
- Air vehicle velocity is between Mach 0 to 1.2
- Bay Power Dissipations 5 kW Total
- Hot-Day Ambient Temperature: 100 degF @ sea-level
- Mach #: 0.35
- Max Air Exit Temperature: 130 degF – Assumption used on other programs based on use of COTS equipment. Also compatible with structural temperature range
- Mdot Air Total: 50 lbm/min
- Adiabatic Bay Walls
- Scoop Pressure Recovery (Propulsion Definition): 95 percent
- Scoop Outlet Air Temperature: 114 degF
- Scoop Outlet Air Pressure: 15.2 psia

# Summary Results

- Max air exit temperature: 137.8 deg. F.
- Max bay penetration area: 57.8 sq. Inch
- Inlet #1 air flow rate: 32.6 lbm/min
- Inlet #2 air flow rate: 17.4 lbm/min

# Thermal Control Analysis Planning Logic

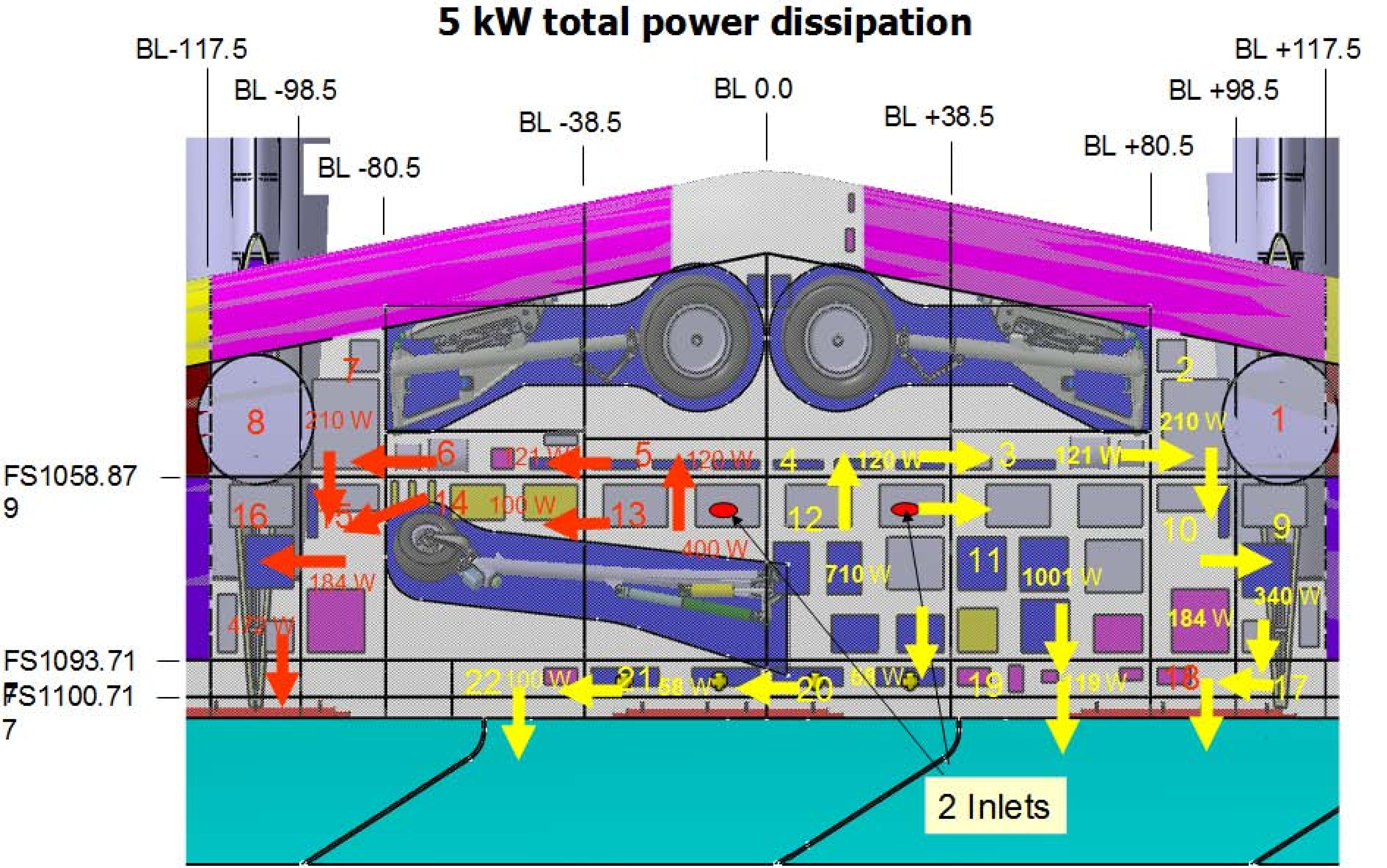


# Thermal Cooling of Avionics Inside AV Equipment Bays

## Approach

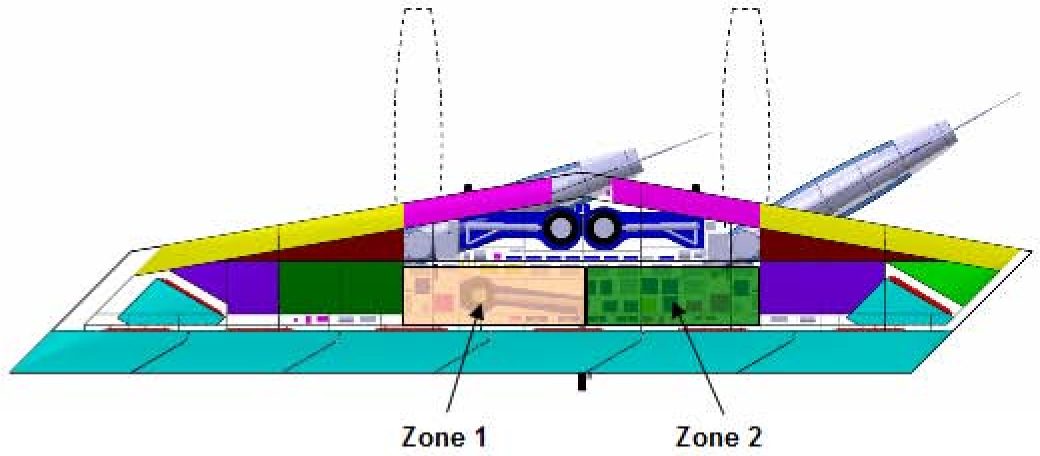
- The AV cabin is divided into a large number of compartments
- The locations and rates of heat produced by Avionics are as specified in each compartment per Master Equipment List
- The waste heat is assumed not to conduct from one compartment to another
- The mass of Avionics are assigned as specified per Master Equipment List, assuming solid aluminum properties

# Cooling Air Flow Path Inside AV Equipment Bays

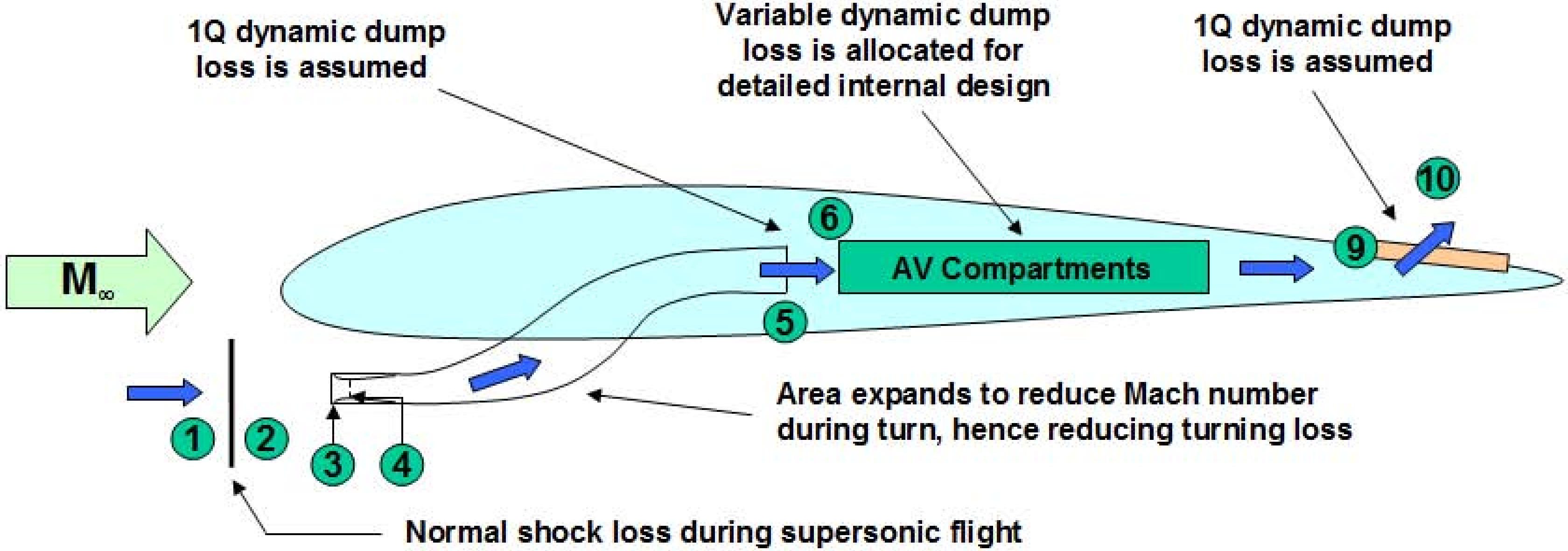


# Cooling Mass Flow Analysis

- **Inlets and exhausts are designed to provide adequate avionics cooling flow to 2 primary cooling zones**
- **Inlet Design**
  - 2 AV inlets located under the wing
  - Variable and passive inlet design
- **Exhaust Design**
  - 4 AV exhausts (or 2 exhaust per inlet) located upper and aft of wing
  - Passive exhaust design with porous surface (fixed exhaust area)

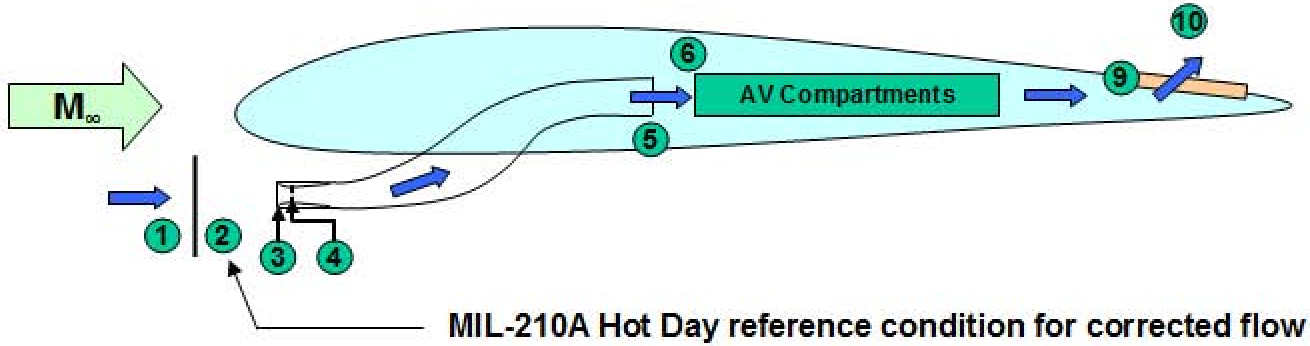


# AV Cooling Design Nomenclature




- Ram scoop design is used as the inlet for avionics cooling flow
- Ram scoop inlet has better pressure recovery compare to flushed inlet during both subsonic and supersonic flights

# AV Cooling Flow Requirements



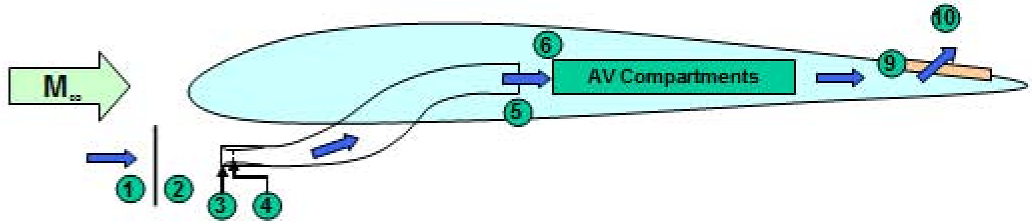

<u>Avionics Cooling Flow Requirements</u>

| Alt (ft) | Mach | Total Flow (ppm) |
|---|---|---|
| 0 | 0.35 | 46 |
| 10,000 | 0.45 | 16 |
| 20,000 | 0.6 | 12 |
| 30,000 | 1.2 | 38 |
| 40,000 | 0.85 | 10 |

<u>Calculated Parameters</u>

| Total Flow (pps) | Total Corrected Flow (pps) |
|---|---|
| 0.767 | 0.742 |
| 0.267 | 0.346 |
| 0.200 | 0.341 |
| 0.633 | 0.927 |
| 0.167 | 0.536 |

# Calculation Results




| Alt | Mach | Req'd Flow (pps) | Single scoop properties based on two ram scoop Design | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Req'd Flow (pps) | Corr. Flow (pps) | MFR | A3 (in²) | CR | A4 (in²) | M4 | A5 (in²) | Pt6 | PR6 | AV Comp. Allocation (Q) | A9 (in²) | W9 (pps) |
| 0 | 0.35 | 46 | 0.383 | 0.371 | 1.000 | 1.924 | 1.1 | 1.749 | 0.39 | 3.499 | 15.15 | 0.947 | 1.023 | 8 | 0.382 |
| 10000 | 0.45 | 16 | 0.133 | 0.173 | 1.000 | 0.73 | 1.1 | 0.663 | 0.51 | 1.327 | 10.65 | 0.917 | 1.266 | 8 | 0.133 |
| 20000 | 0.6 | 12 | 0.100 | 0.17 | 0.987 | 0.599 | 1.1 | 0.544 | 0.7 | 1.089 | 7.502 | 0.87 | 1.544 | 8 | 0.1 |
| 30000 | 1.2 | 38 | 0.316 | 0.467 | 0.849 | 1.639 | 1.1 | 1.49 | 0.7 | 2.98 | 9.139 | 0.864 | 7.935 | 8 | 0.316 |
| 40000 | 0.85 | 10 | 0.083 | 0.268 | 0.847 | 0.941 | 1.1 | 0.856 | 0.7 | 1.712 | 3.8 | 0.87 | 4.402 | 8 | 0.083 |

MFR limited to 1

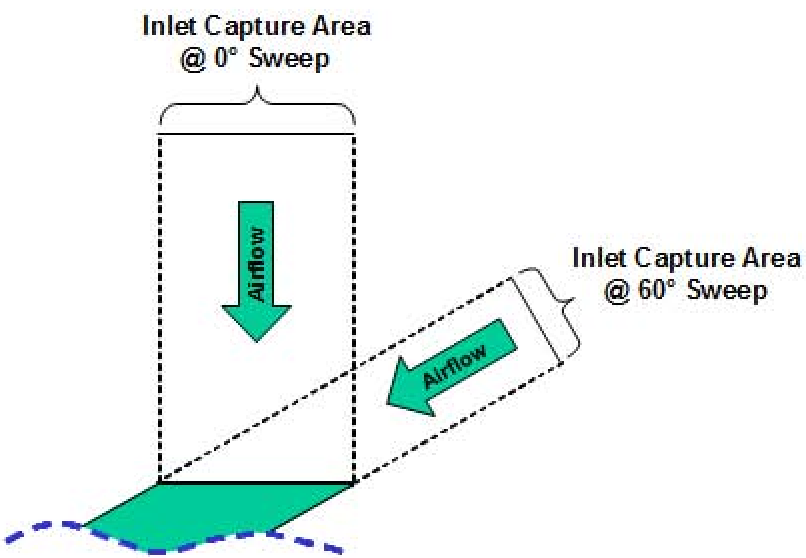
Throat designed to maximum of M0.7 for better inlet performance and stability

Conservation of Mass satisfied

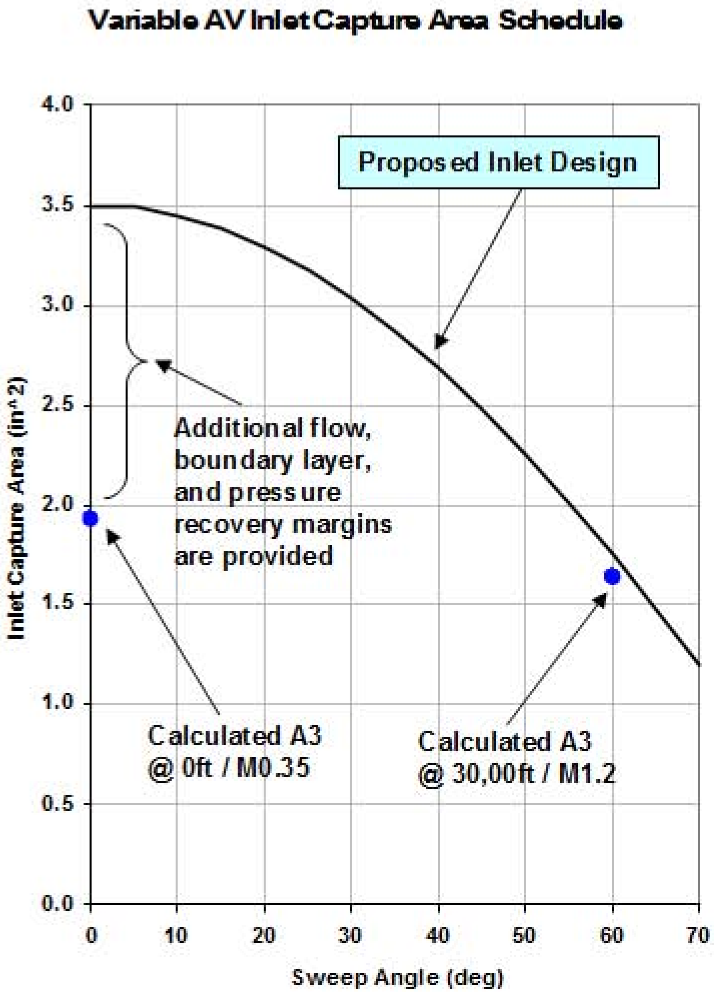
- **Large area variations are observed among design points**
- **Variable inlet would result in better inlet matching for required AV cooling flow**

# AV Inlet Design

## AV Inlet Schematic (Top View)




- Scarf ram scoop becomes a variable inlet via vehicle sweep angle
- The variable ram scoop inlet schedule has desired characteristic
  - Larger inlet capture area at subsonic
  - Smaller inlet capture area at supersonic
- Ram scoop flow path is designed for supersonic sweep to reduce pressure loss

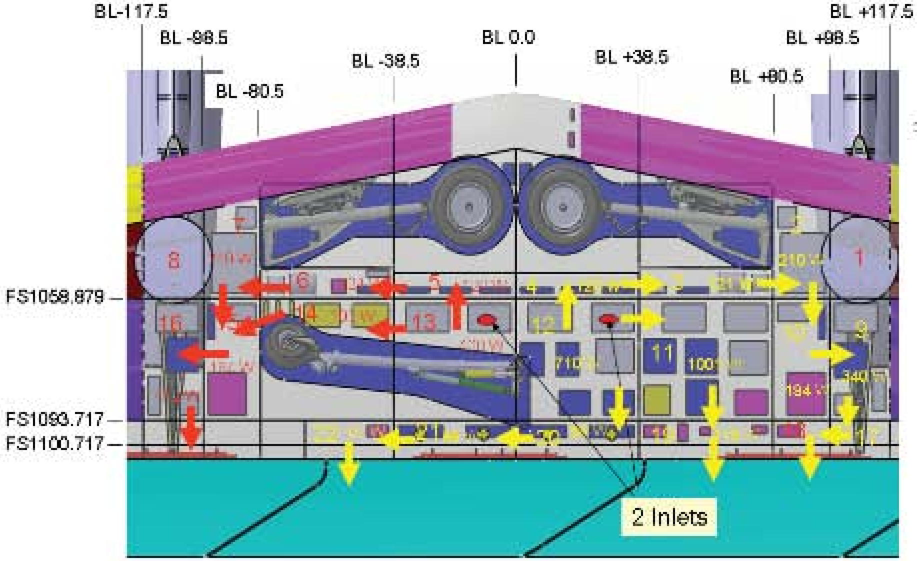


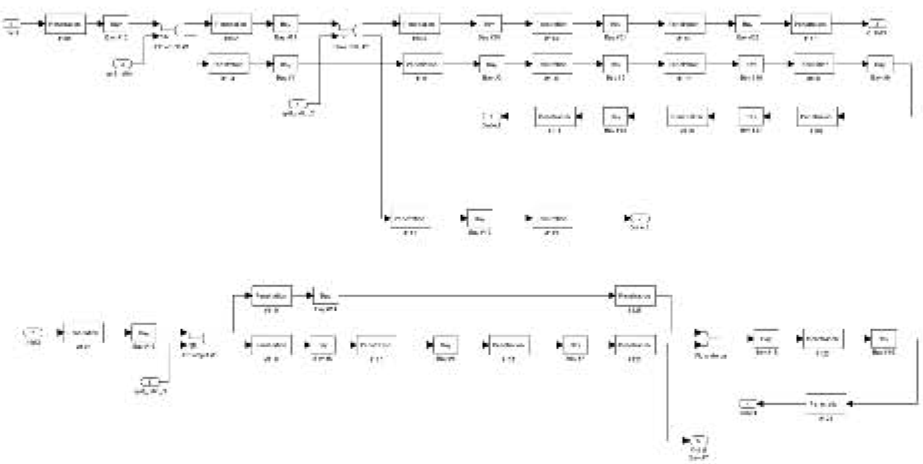
# AV Bay Penetration Sizing: Modeling & Equations

- ECS Toolbox Used to Perform AV Bay Penetration Sizing Analysis
- ECS Toolbox was derived from AECS Fortran Code Using MATLAB/SIMULINK
- Penetration Sizing Modeled as (22) Bays and (25) Penetrations
- Bays Modeled as discrete heat loads without pressure drop
- Penetrations Modeled as Valves with External "K" Factor [Eq. 2: deltap(psid) = K * Mdot(lbm/min) ]
- Flow-Split Ratio's Used as State Variables
- Air Outlet Exit Temperatures and Pressures Used as Error Variables
- Penetration Flow Data Used to Compute Orifice Flow Function [Mdot(ppm)*sqrt(T_total(degR)) / ( Area(sq.inch)*P_total(psia) ) ]
- Empirical Orifice Data Used to Iteratively Solve For Penetration Area

# AV Bay Penetration Sizing For Hot-Day Low Altitude Cruise Case

- Altitude: Sea-Level
- Mach #: 0.35
- T_amb: 100 degF
- Total Air Flow Rate: 50 PPM (use 46 PPM from cooling mass flow calculation + margin)
- Scoop Pressure Recovery: 95 %
- Utilized ECS Toolbox, Steady-State Analysis
- Sized Penetrations Based On 130 degF Exit Air Temperature & P_amb Exit Pressure



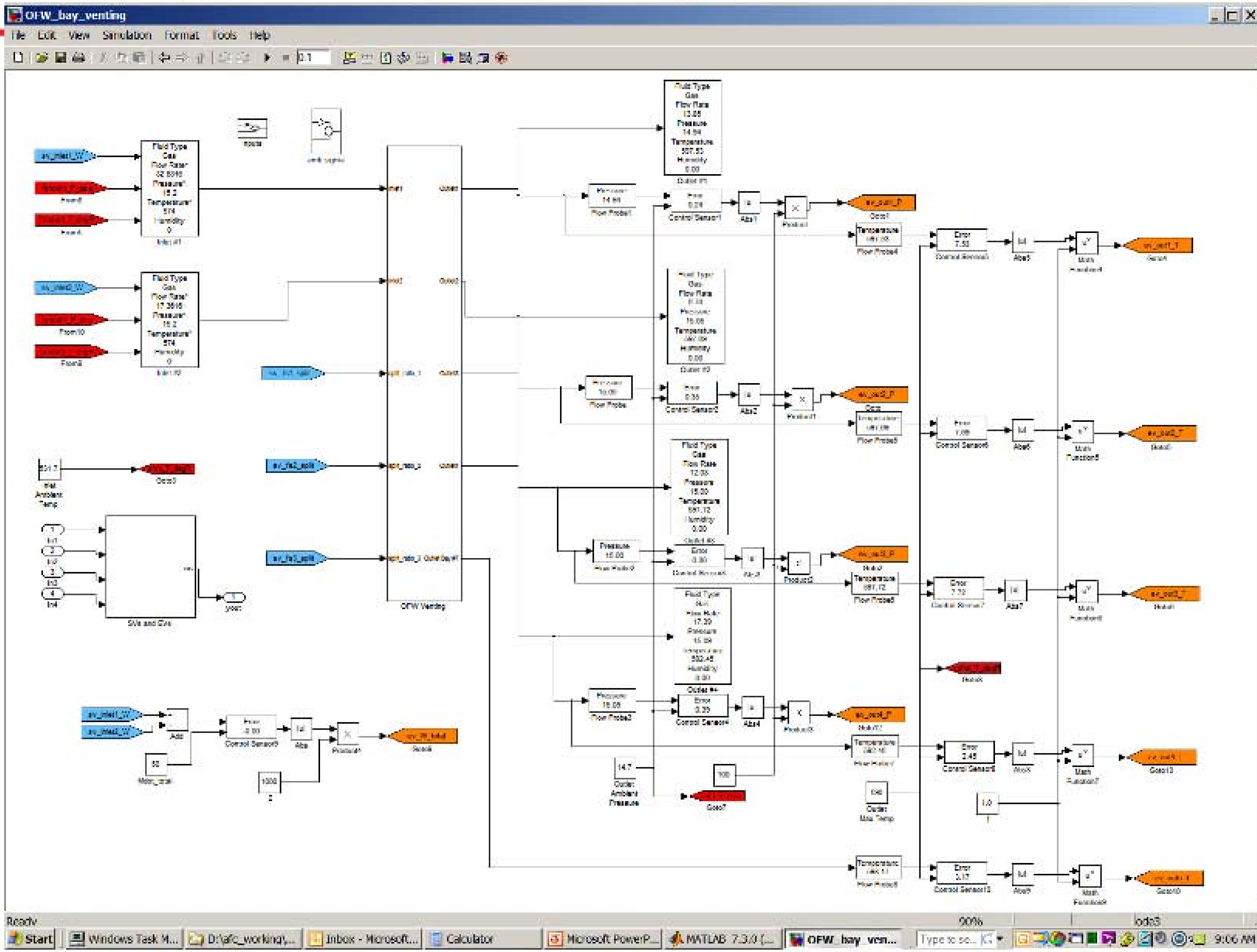
# AV Bay Penetration Sizing For Hot-Day Low Altitude Cruise Case: (Cont.)

## (Mach #: 0.35, Alt: Sea-Level, Air Flow Rate: 50 PPM, Tamb: 100 degF)

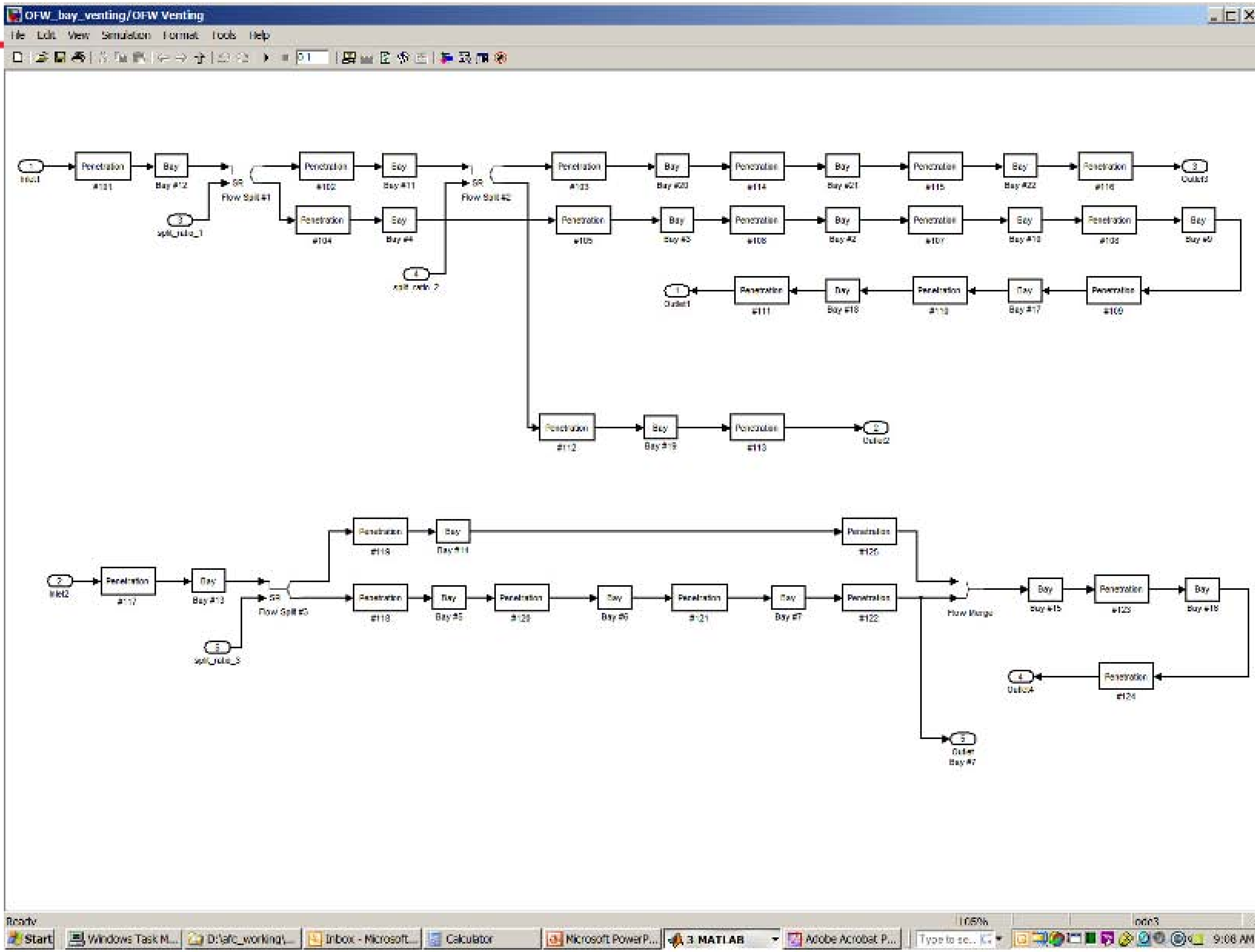
| Bay ID# | Power (W) | Bay Exit Temperature (degF) |
|---|---|---|
| 1 | 0 | N/A |
| 2 | 227 | 128.0 |
| 3 | 131 | 124.1 |
| 4 | 130 | 121.8 |
| 5 | 130 | 123.5 |
| 6 | 131 | 127.1 |
| 7 | 227 | 133.4 |
| 8 | 0 | N/A |
| 9 | 367 | 137.8 |
| 10 | 199 | 131.5 |
| 11 | 1081 | 133.0 |
| 12 | 767 | 119.6 |
| 13 | 432 | 119.9 |
| 14 | 108 | 122.8 |
| 15 | 199 | 125.4 |
| 16 | 510 | 132.2 |
| 17 | 0 | 137.8 |
| 18 | 0 | 137.8 |
| 19 | 129 | 137.5 |
| 20 | 63 | 134.2 |
| 21 | 63 | 135.4 |
| 22 | 108 | 137.5 |

| Penetration ID# | From Bay ID# | To Bay ID# | Penetration Area (sq. inch) | Penetration Dia. (inch) |
|---|---|---|---|---|
| 101 | Inlet #1 (RHS) | 12 | 12.75 | 4.03 |
| 102 | 12 | 11 | 20.26 | 5.08 |
| 103 | 12 | 20 | 32.03 | 6.39 |
| 104 | 12 | 4 | 28.26 | 6.00 |
| 105 | 4 | 3 | 28.47 | 6.02 |
| 106 | 3 | 2 | 28.37 | 6.01 |
| 107 | 2 | 10 | 28.47 | 6.02 |
| 108 | 10 | 9 | 28.70 | 6.05 |
| 109 | 9 | 17 | 28.70 | 6.05 |
| 110 | 17 | 18 | 28.70 | 6.05 |
| 111 | 18 | Outlet #1 (RHS) | 28.86 | 6.06 |
| 112 | 11 | 19 | 57.57 | 8.56 |
| 113 | 19 | Outlet #2 | 57.78 | 8.58 |
| 114 | 20 | 21 | 31.84 | 6.37 |
| 115 | 21 | 22 | 32.09 | 6.39 |
| 116 | 22 | Outlet #3 | 31.93 | 6.38 |
| 117 | Inlet #2 (LHS) | 13 | 22.15 | 5.31 |
| 118 | 13 | 5 | 44.97 | 7.57 |
| 119 | 13 | 14 | 43.26 | 7.42 |
| 120 | 5 | 6 | 45.74 | 7.63 |
| 121 | 6 | 7 | 45.24 | 7.59 |
| 122 | 7 | 15 | 46.12 | 7.66 |
| 123 | 15 | 16 | 21.87 | 5.28 |
| 124 | 16 | Outlet #4 (LHS) | 22.00 | 5.29 |
| 125 | 14 | 15 | 43.93 | 7.48 |

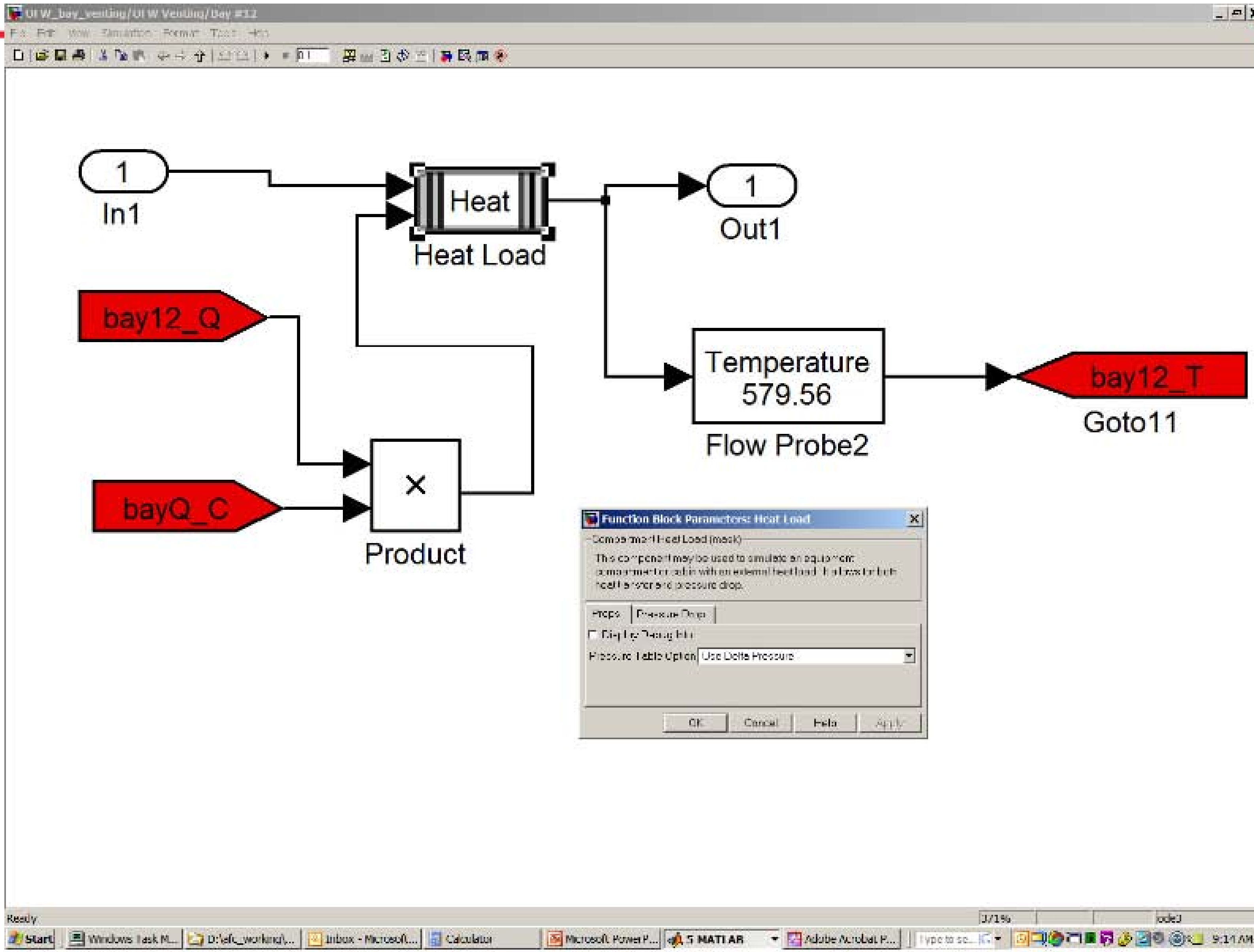
# AV Bay Penetration Sizing – ECS Toolbox: TOP



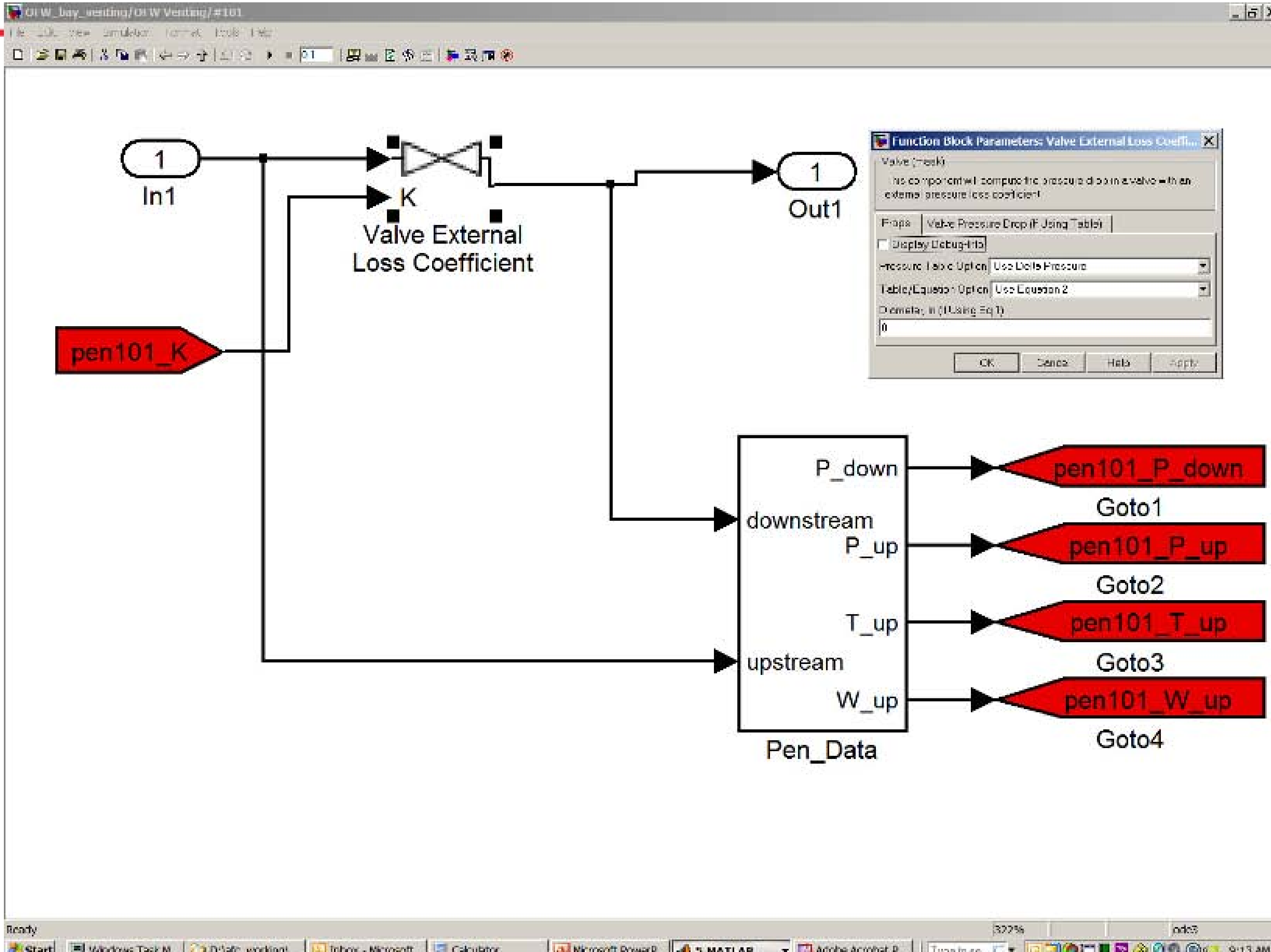
# AV Bay Penetration Sizing – ECS Toolbox: Bays & Penetrations



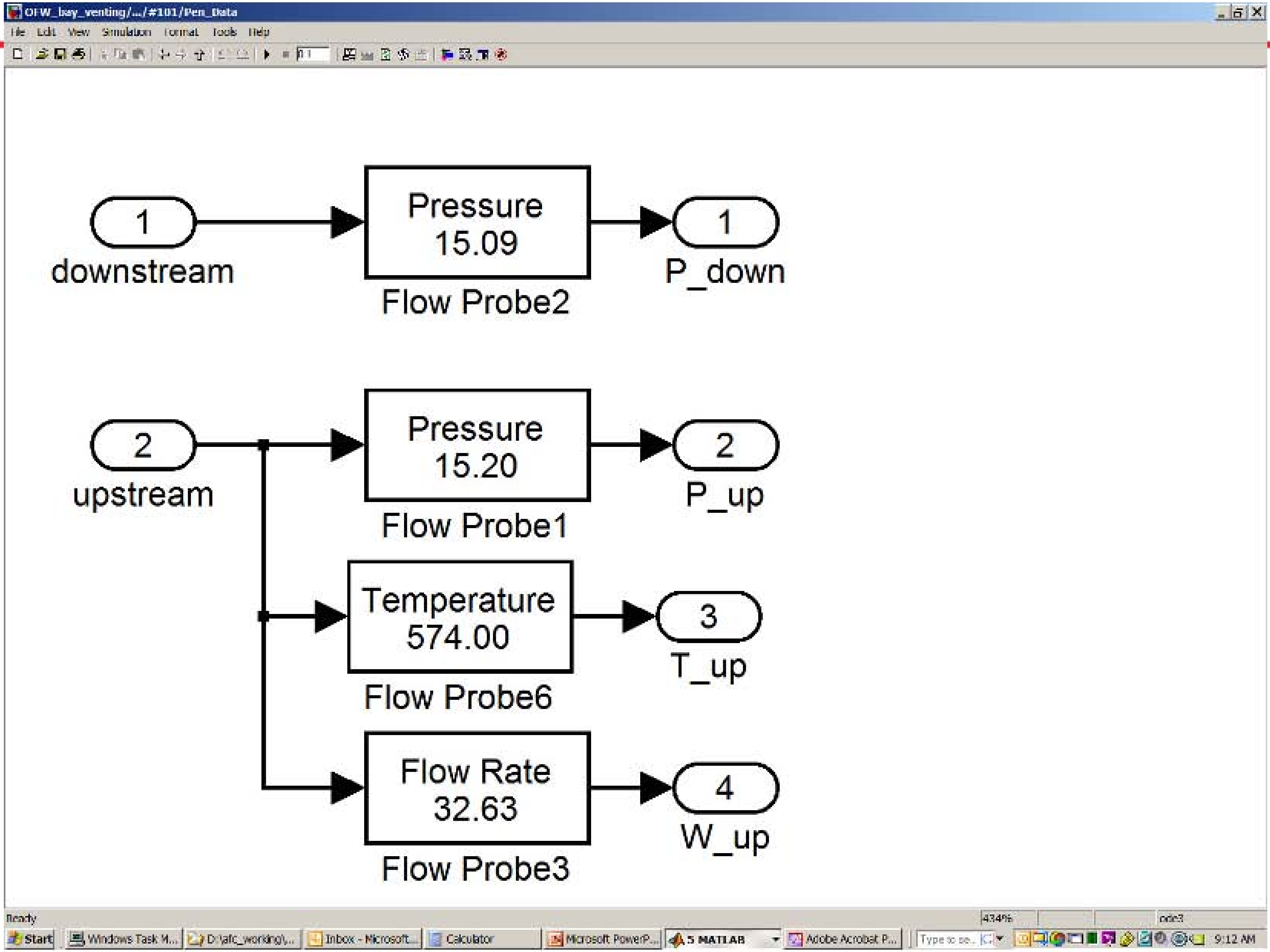
# AV Bay Penetration Sizing – ECS Toolbox: Bays



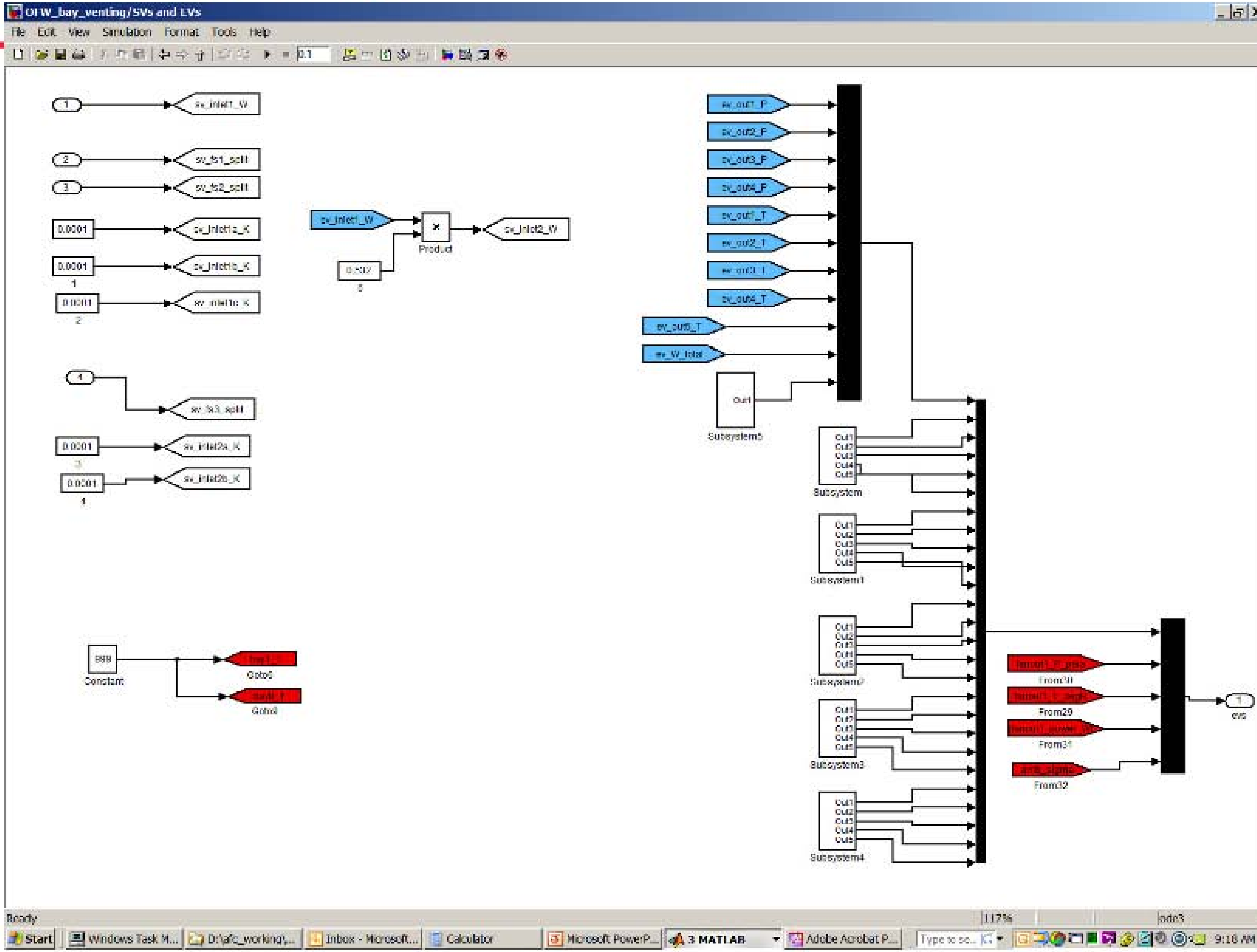
# AV Bay Penetration Sizing – ECS Toolbox: Penetrations



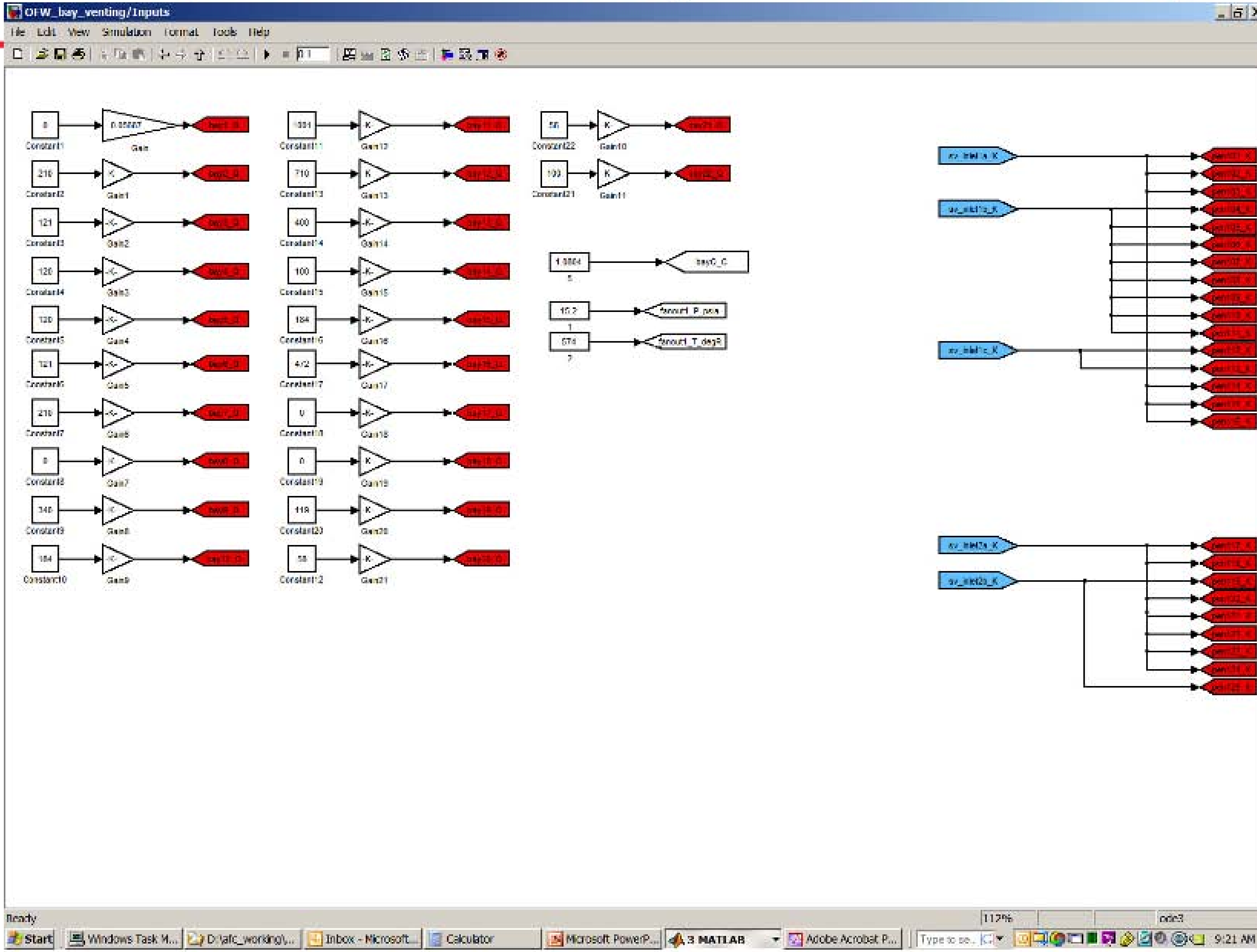
# AV Bay Penetration Sizing – ECS Toolbox: Pen_Data



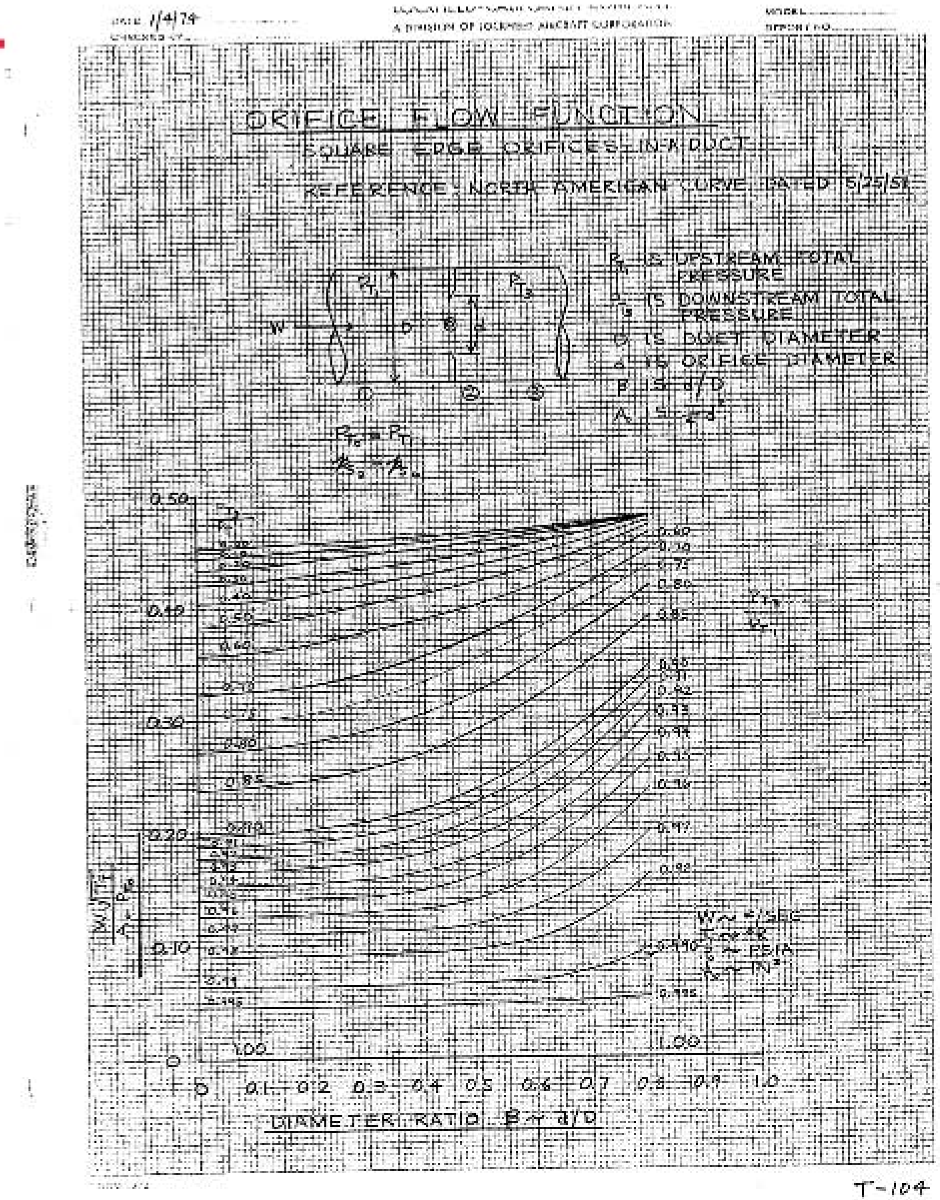
# AV Bay Penetration Sizing – ECS Toolbox: State & Error Variables



# AV Bay Penetration Sizing – ECS Toolbox: Inputs



# AV Bay Penetration Sizing: Empirical Orifice Data / Orifice Flow Function

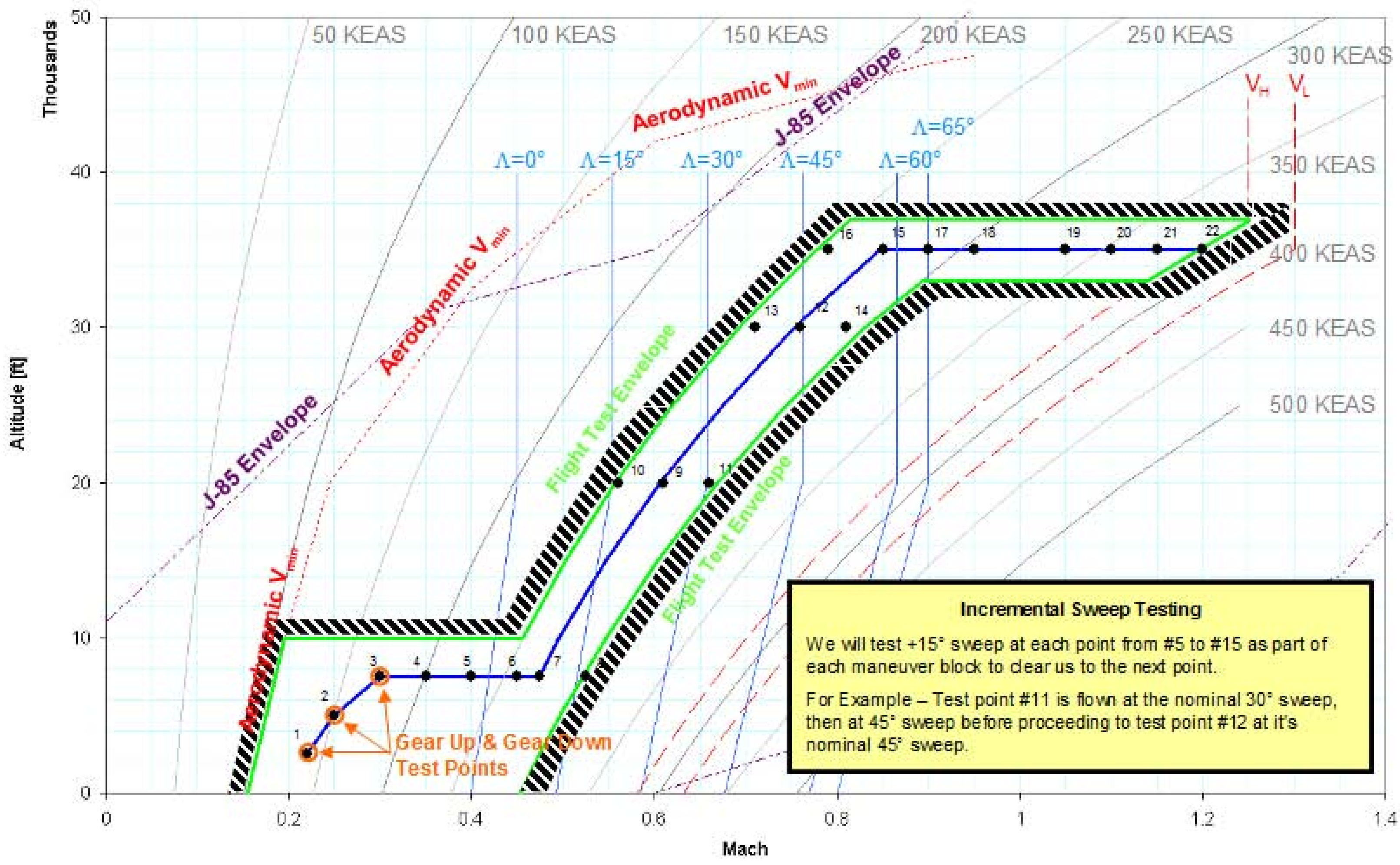


## AV: BAY AIR TEMPERATURE ASSUMPTIONS

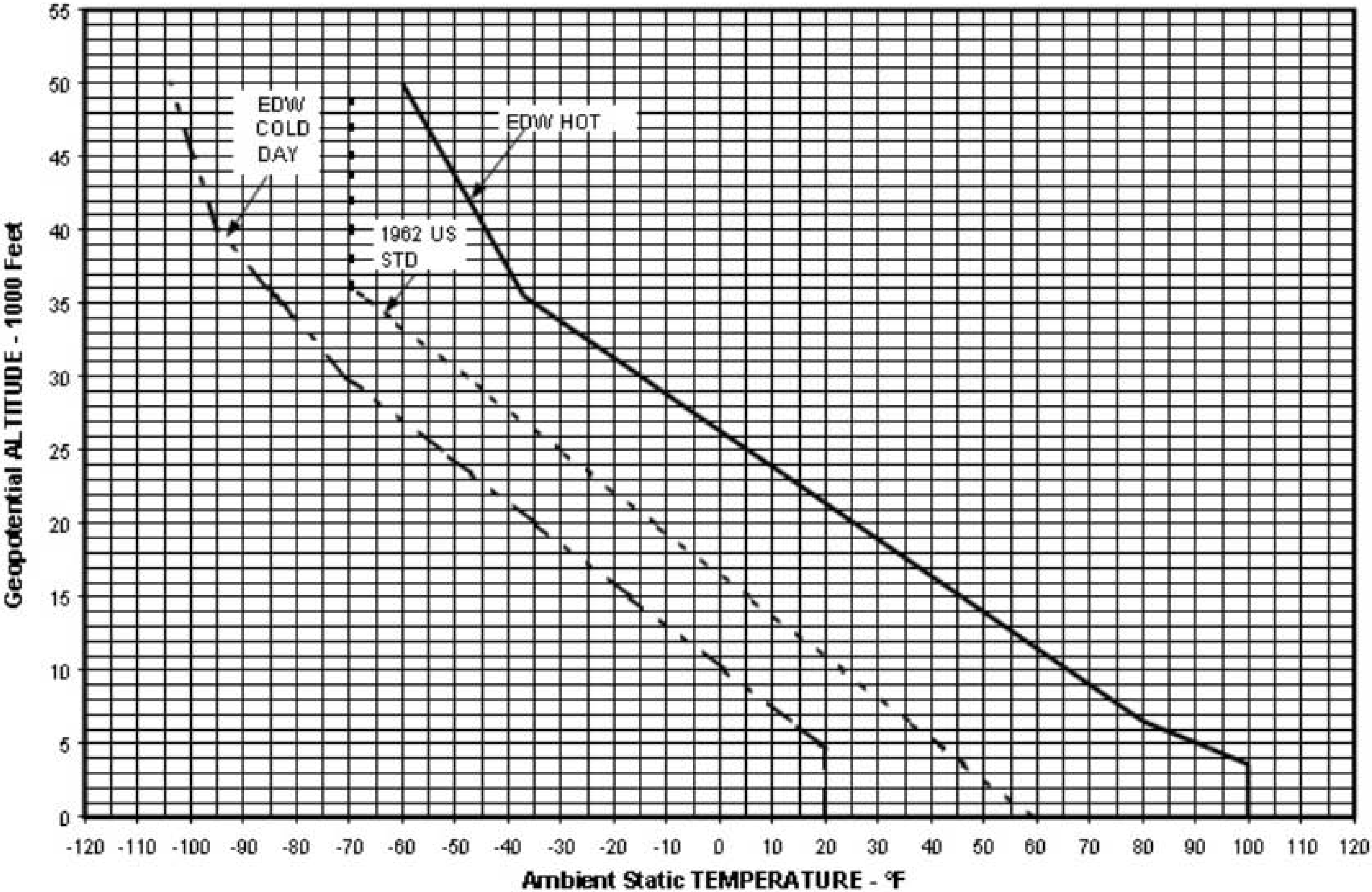
- M5 Flight Test Profile points (1) through (22)
- Prior calculated bay-to-bay penetration areas
- Prior defined bay interior power dissipations
- Steady-state flow assumed at each of points (1) thru (22)
- No convective heat transfer to the bay interior wall surfaces
- EAFB Hot/Cold-Day Atmosphere Model (see attached)
- Ground Cold Air Cart: 40 degF @ 50 ppm & 0.5 psid
- +136 degF Max & -34 degF Min Op Extremes
- Recommend: +160 degF Max & -40 degF Min Non-Op/Storage Extremes

# Flight Test Points

## Milestone 5



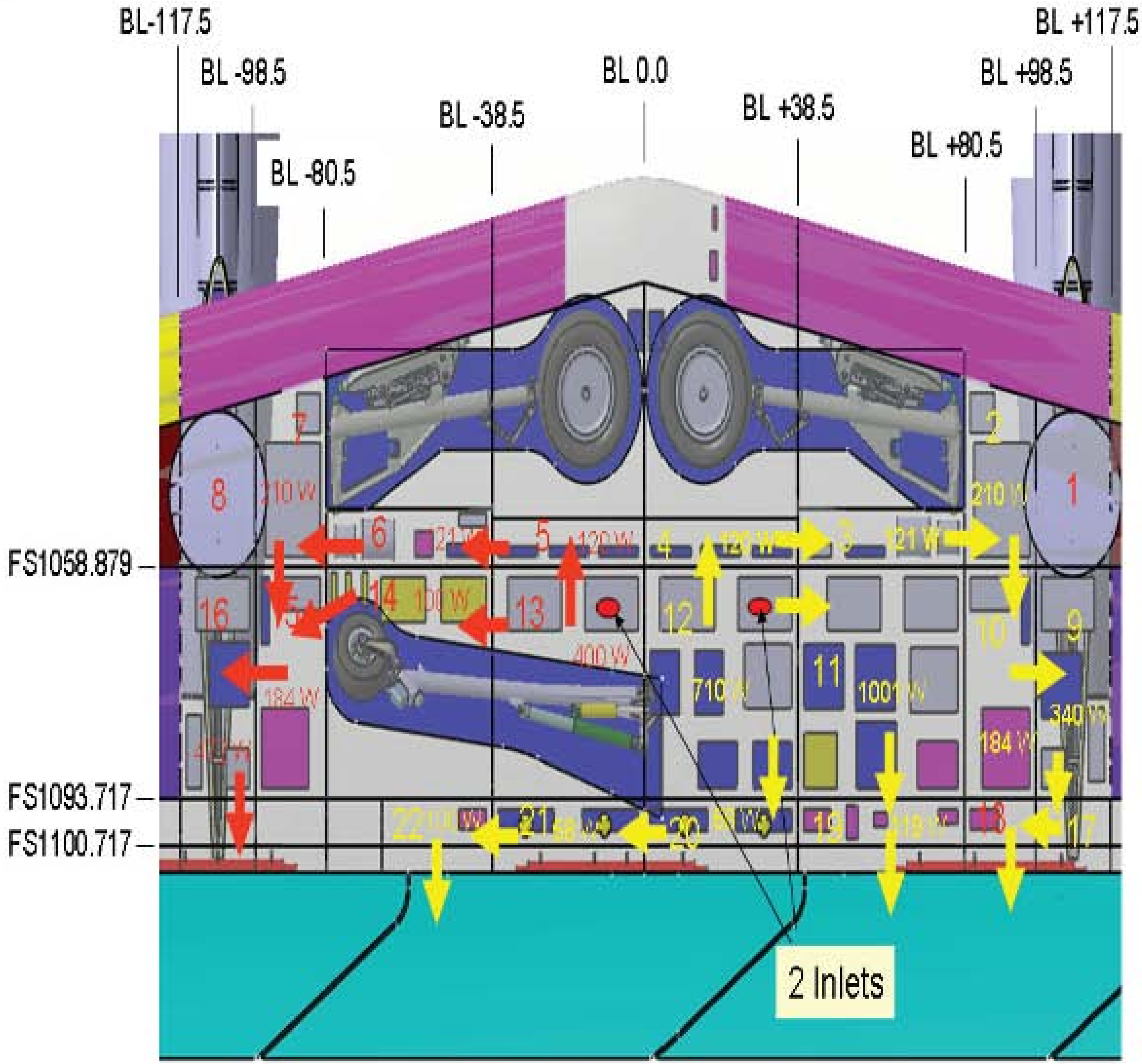
# AV: EAFB HOT/COLD-DAY ATMOSPHERE MODEL



# AV: BAY AIR TEMPERATURE EXTREMES

| | OVERALL | |
|---|---|---|
| Bay (#) | T_max (degF) | T_min (degF) |
| Bay_2 | 122 | -27 |
| Bay_3 | 117 | -30 |
| Bay_4 | 114 | -31 |
| Bay_5 | 111 | -33 |
| Bay_6 | 113 | -32 |
| Bay_7 | 116 | -30 |
| Bay_9 | 136 | -20 |
| Bay_10 | 127 | -24 |
| Bay_11 | 123 | -27 |
| Bay_12 | 111 | -33 |
| Bay_13 | 109 | -34 |
| Bay_14 | 111 | -32 |
| Bay_15 | 114 | -31 |
| Bay_16 | 120 | -28 |
| Bay_17 | 136 | -20 |
| Bay_18 | 136 | -20 |
| Bay_19 | 125 | -25 |
| Bay_20 | 124 | -26 |
| Bay_21 | 126 | -25 |
| Bay_22 | 129 | -24 |

| | | |
|---|---|---|
| T_max: | 136 | n/a |
| T_min: | n/a | -34 |



# AV: BAY AIR TEMPERATURE RESULT SUMMARY

| | OVERALL | | HOT-DAY | | COLD-DAY | | GROUND-CART |
|---|---|---|---|---|---|---|---|
| Bay (#) | T_max (degF) | T_min (degF) | T_outlet_max (degF) | T_outlet_min (degF) | T_outlet_max (degF) | T_outlet_min (degF) | T_inlet = 40 degF @ 50 PPM (degF) |
| Bay_2 | 122 | -27 | 122 | 27 | 44 | -27 | 62 |
| Bay_3 | 117 | -30 | 117 | 24 | 42 | -30 | 55 |
| Bay_4 | 114 | -31 | 114 | 22 | 41 | -31 | 51 |
| Bay_5 | 111 | -33 | 111 | 21 | 39 | -33 | 46 |
| Bay_6 | 113 | -32 | 113 | 22 | 40 | -32 | 48 |
| Bay_7 | 116 | -30 | 116 | 23 | 42 | -30 | 52 |
| Bay_9 | 136 | -20 | 136 | 33 | 55 | -20 | 79 |
| Bay_10 | 127 | -24 | 127 | 29 | 47 | -24 | 68 |
| Bay_11 | 123 | -27 | 123 | 27 | 45 | -27 | 62 |
| Bay_12 | 111 | -33 | 111 | 21 | 39 | -33 | 47 |
| Bay_13 | 109 | -34 | 109 | 20 | 38 | -34 | 44 |
| Bay_14 | 111 | -32 | 111 | 21 | 40 | -32 | 47 |
| Bay_15 | 114 | -31 | 114 | 22 | 41 | -31 | 49 |
| Bay_16 | 120 | -28 | 120 | 25 | 43 | -28 | 56 |
| Bay_17 | 136 | -20 | 136 | 33 | 55 | -20 | 79 |
| Bay_18 | 136 | -20 | 136 | 33 | 55 | -20 | 79 |
| Bay_19 | 125 | -25 | 125 | 28 | 46 | -25 | 65 |
| Bay_20 | 124 | -26 | 124 | 28 | 45 | -26 | 64 |
| Bay_21 | 126 | -25 | 126 | 28 | 46 | -25 | 66 |
| Bay_22 | 129 | -24 | 129 | 30 | 48 | -24 | 70 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T_max: | 136 | n/a | 136 | n/a | 55 | n/a | 79 |
| T_min: | n/a | -34 | n/a | 20 | n/a | -34 | 44 |