Escape Slide Performance at High Altitude

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ESCAPE SLIDE PERFORMANCE AT HIGH ALTITUDE

- Questions were raised with FAA-Transport Airplane Directorate (TAD) concerning escape slide performance at high altitude airports.
- Escape slide qualification and certification testing by major slide and airplane manufacturers is typically performed at altitudes close to sea level.
- The basic issue at high altitudes where the air is thinner is: Does the escape slide inflation system inflate the slide to an acceptable pressure?
- Performance testing of escape slides at high altitudes was proposed.
- Goodrich and FAA-CAMI collaborated in an effort to understand high altitude slide performance.

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ESCAPE SLIDE SYSTEM

Two major components of an escape slide system are the inflation system and the inflatable assembly.

SLIDE INFLATABLE ASSEMBLY

The inflatable is the air-holding chamber which is pressurized by the inflation system to provide the pathway from the exit to the ground.

The inflatable has appropriate inflation restraining devices to control the inflation sequence and a pressure relief valve to prevent over-inflation.

The inflatable has other accessories (handles, patches, straps, lights, etc.) which serve other slide purposes.

INFLATION SYSTEM

The inflation system consists of a pressurized cylinder storing inflation gas which is connected to an air entrainment device (aka an aspirator) by a hose.

While sufficient stored gas could (theoretically) be provided for inflation under any environmental conditions, the weight and volume of gas required would be significant. To lessen the need for stored gas, the aspirator is used to draw in outside air to assist in the inflation.

To protect against over-pressurization, a pressure relief valve (PRV) is provided. Typically, this is actuated during an ambient deployment and will affect the final pressure reading.

INFLATION THEORY

Air entrainment at high altitudes has been predicted based upon data collected at low altitudes.

Computational Fluid Dynamics (CFD) programs have been applied to low altitude inflation data to determine air entrainment efficiencies needed to achieve full slide inflation.

As noted earlier, at high altitudes, the air is less dense. Thus, a part of the question is: Will the lesser mass of air being entrained into the aspirator provide adequate inflation pressure?

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INFLATION THEORY (Cont'd)

Complicating the analysis of performance at high altitudes are several unknowns:

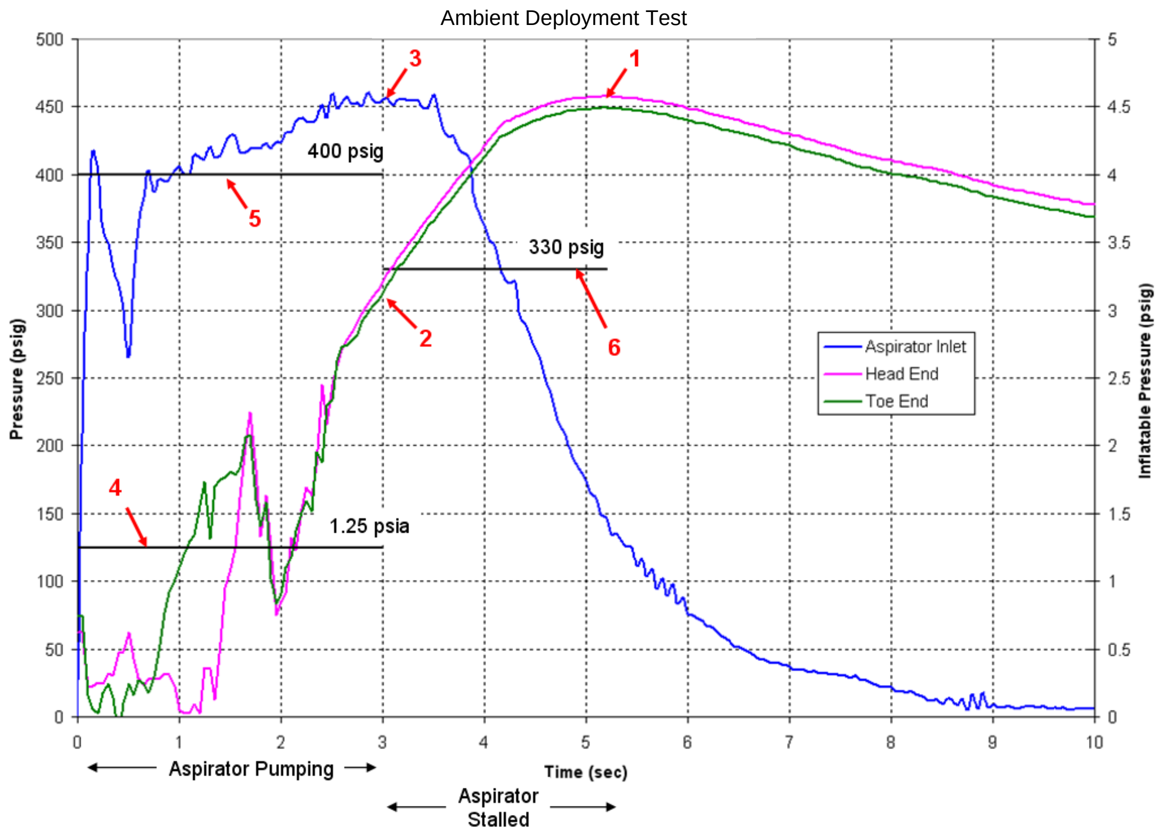
How do inflation restraining devices affect inflation system efficiencies and overall performance?

How will the aspirator respond to the levels of inlet pressure from the pressurized inflation cylinder and back pressure within the inflatable assembly?

Will the aspirator "stall" (close its "doors" to retain inflation pressure) early limiting ambient air entrainment?

Aspirator Operation During Slide Deployment

- Below is an ambient deployment at an altitude of less than 1500 ft (457 m)



Aspirator Pumping

Aspirator Stalled

1. Maximum slide pressure during deployment
2. Slide backpressure at aspirator stall
3. Aspirator inlet pressure at aspirator stall
4. Average slide backpressure while aspirator is not stalled
5. Average aspirator inlet pressure while aspirator is not stalled
6. Average aspirator inlet pressure while aspirator is stalled

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Calculated Performance from Deployment

- $M_{\text{total in slide}} = M_{\text{secondary}} + M_{\text{primary before stall}} + M_{\text{primary after stall}}$
- $M_{\text{secondary}}$ = 1.9 lbm/sec * 3 sec = 5.7 lbm (2.59 kg)
- $M_{\text{primary before stall}}$ = 0.68 lbm/sec * 3 sec = 2.04 lbm (0.93 kg)
- $M_{\text{primary after stall}}$ = 0.55 lbm/sec * 2.2 sec = 1.21 lbm (0.58 kg)
- $M_{\text{total in slide}}$ is thus: 8.94 lbm (4.06 kg)
- This mass gives us the maximum slide pressure from the figure equal to ~4.6 psig (~31.7 kPag) or 18.8 psia (129.6 kPaa).

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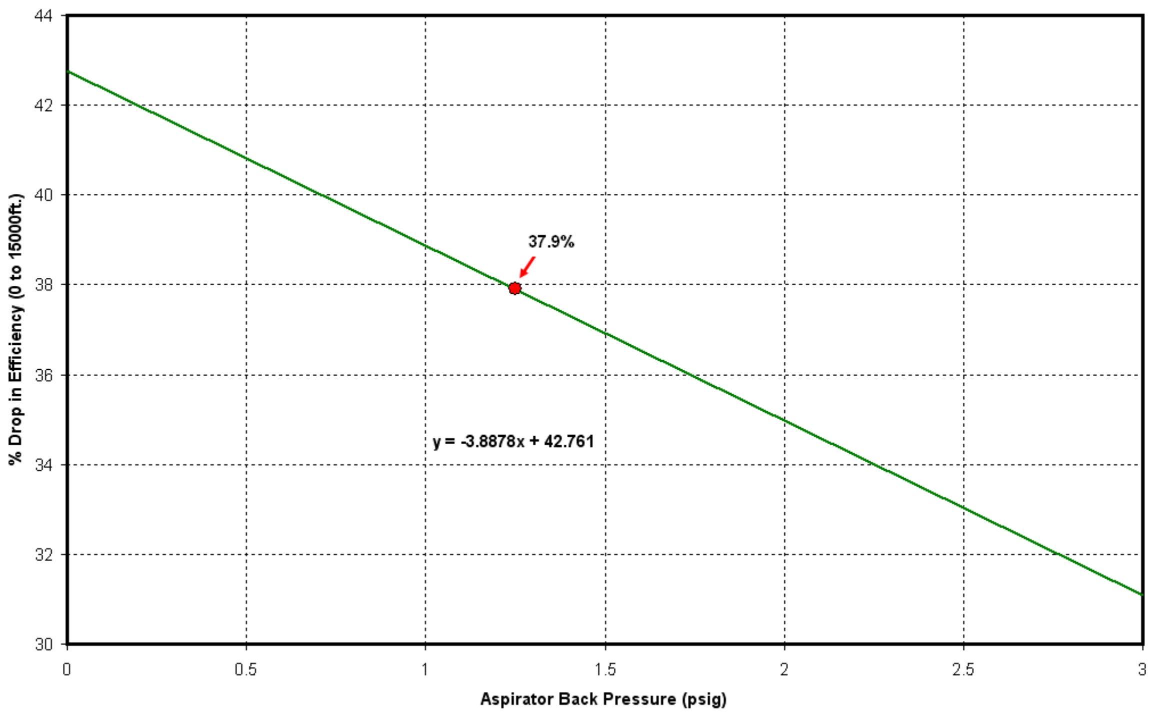
Performance Change with Altitude Change

- Due to the altitude change two things happen:

  1. The atmospheric pressure drops from 14.2 psia (test site ambient) to 8.3 psia (97.9 to 57.2 kPaa)
  2. The aspirator efficiency decreases

- Aspirator efficiency drop was calculated using CFD knowing that the ambient air density drops with altitude increase leading to lower masses of gas being entrained by the aspirator.



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Predicted Performance at 15 000 ft (4572 m)

- Only the secondary gas mass is affected by altitude changes
- Assuming similar inlet pressure and slide back pressure as those shown earlier:
- $M_{\text{secondary at altitude}} = M_{\text{secondary at test site}} * (1 – 0.352) = 3.69$ lbm (1.67 kg)
- $M_{\text{primary before stall}}$: Same as at test site
- $M_{\text{primary after stall}}$: Same as at test site
- $M_{\text{total at altitude}} = M_{\text{secondary}} + M_{\text{primary before stall}} + M_{\text{primary after stall}}$

  $= 6.93$ lbm (3.14 kg)

Predicted Slide Pressure

- Using the ideal gas law, we now obtain the slide pressure at 15 000 ft (4752 m).

$$P_2 = \frac{P_1 m_2 T_2}{m_1 T_1}$$

P_1 is the absolute pressure in the slide at test site	P_1 = 18.8 psia (129.6 kpaa)
P_2 is the absolute pressure in the slide at 15 000 ft (4572 m)	P_2 = Unknown
m_1 is the total gas mass in the inflatable at test site	m_1 = 8.94 lbm (4.06 kg)
m_2 is the total gas mass in the inflatable at 15 000 ft (4572 m)	m_2 = 6.93 lbm (3.14 kg)
T_1 is the temperature at test site	T_1 = 530 R
T_2 is the temperature at 15 000 ft (4752 m)	T_2 = 480 R

- Resulting slide pressure at 15 000 ft (4572 m) is, thus:

  13.2 psia (91.0 kPaa) or 4.9 psig (33.8 kPag)

  (For normal operation, the target range is: 3.0 – 5.2 psig (20.7-35.9 kPag))

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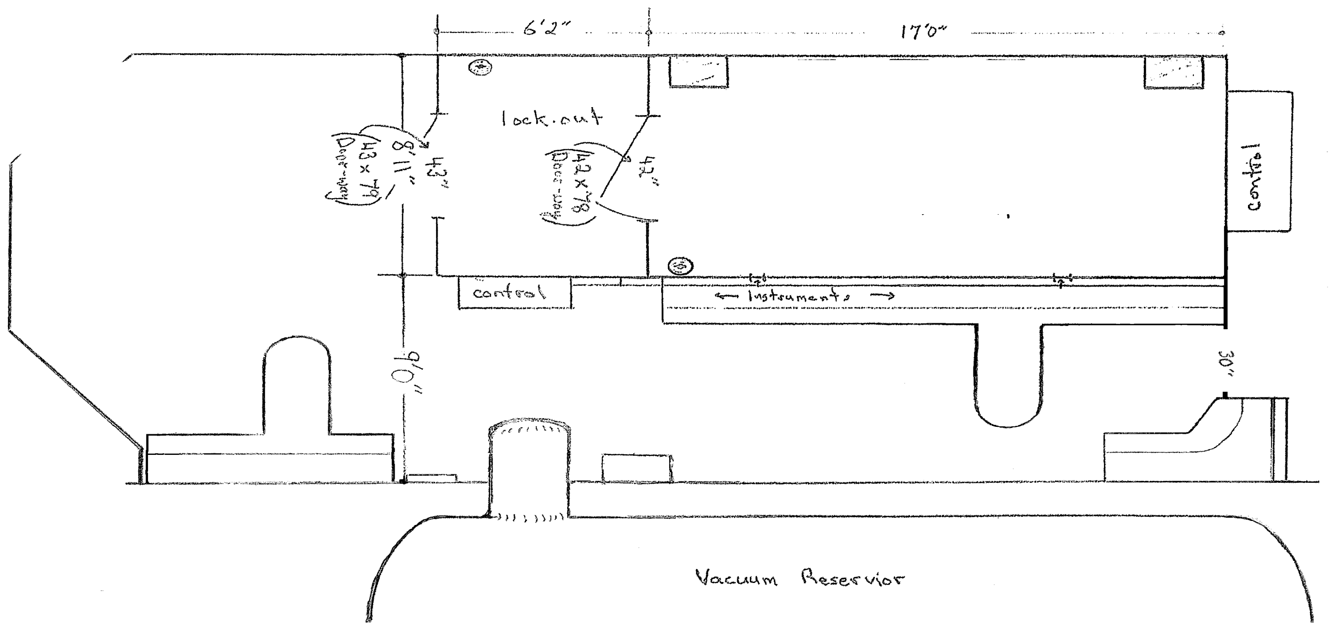
ALTITUDE TESTING

FAA-CAMI altitude chamber:

Slide length could not be more than 17 ft (5.18 m) for deployment or 23 ft (7 m) for a “flat fire”

Chamber temperature is maintained at 72º F (22.2º C) for all altitudes



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SLIDE DEPLOYMENT SET-UP IN CHAMBER

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SLIDE DEPLOYMENT IN CHAMBER

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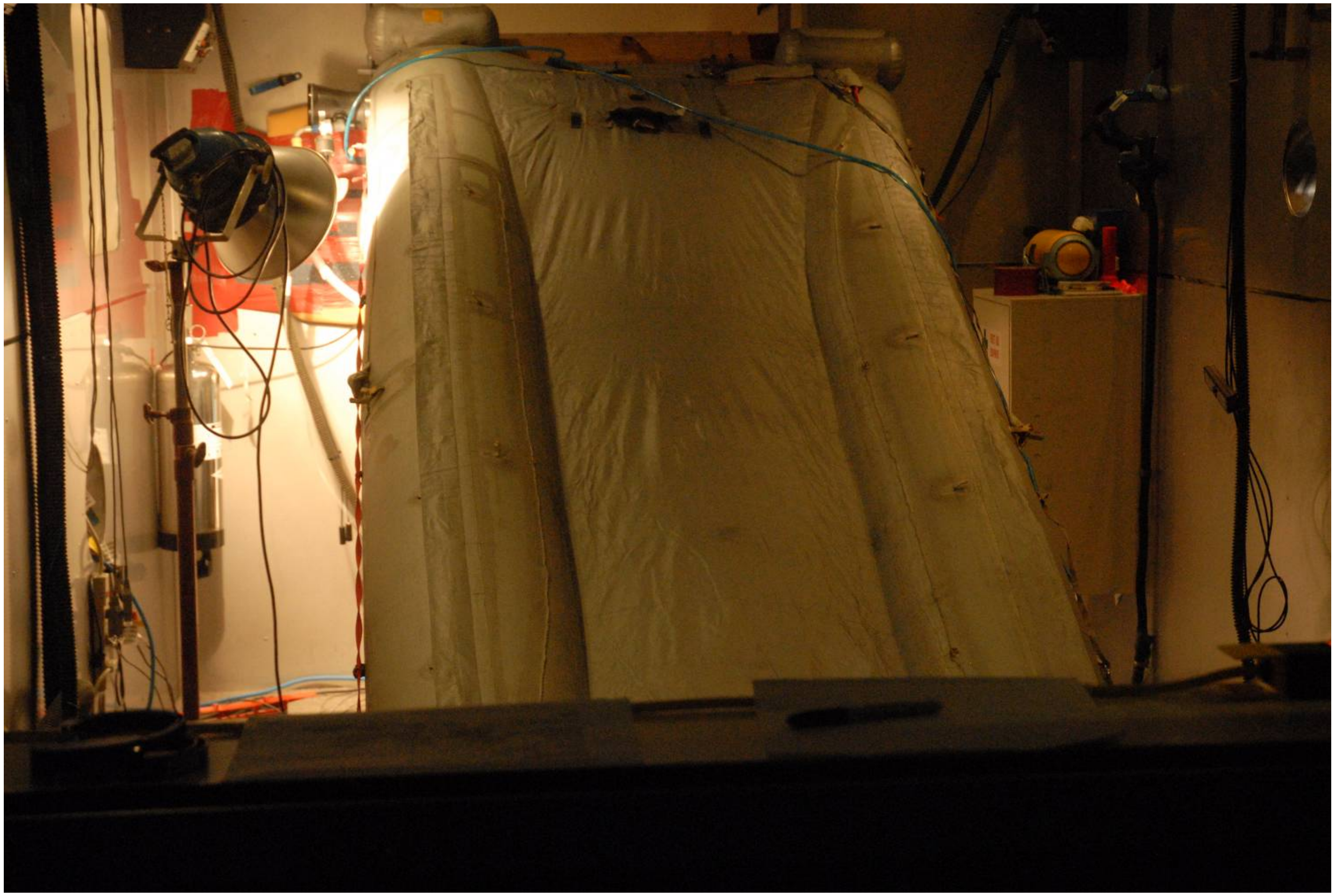
DEPLOYED SLIDE



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"FLAT FIRE" (UNRESTRAINED SLIDE)

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“FLAT FIRE” (UNRESTRAINED SLIDE)

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“FLAT FIRE” OF LONGER SLIDE

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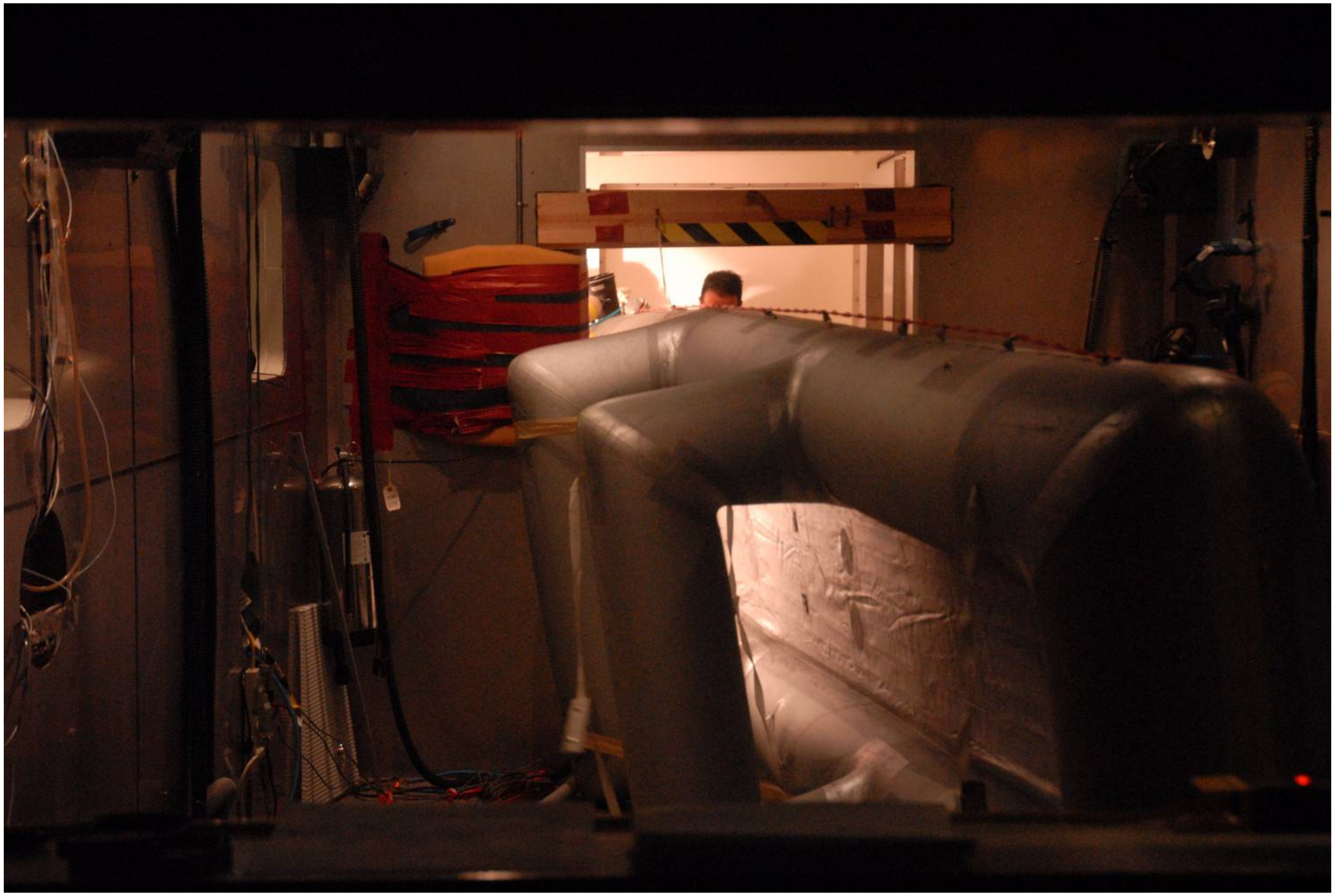
LONGER SLIDE INFLATED



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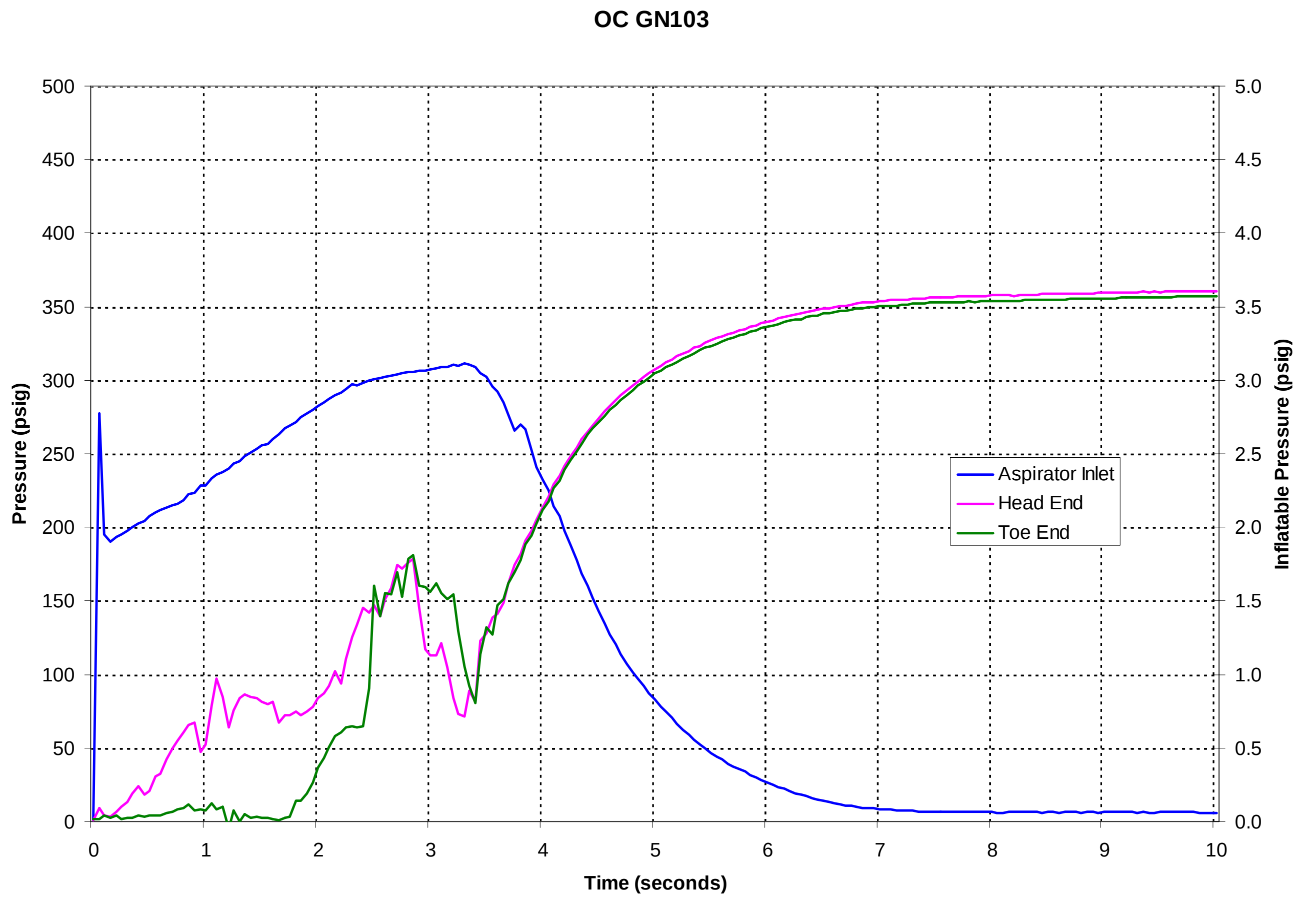
PARTIAL DEPLOYMENT – TEST SITE



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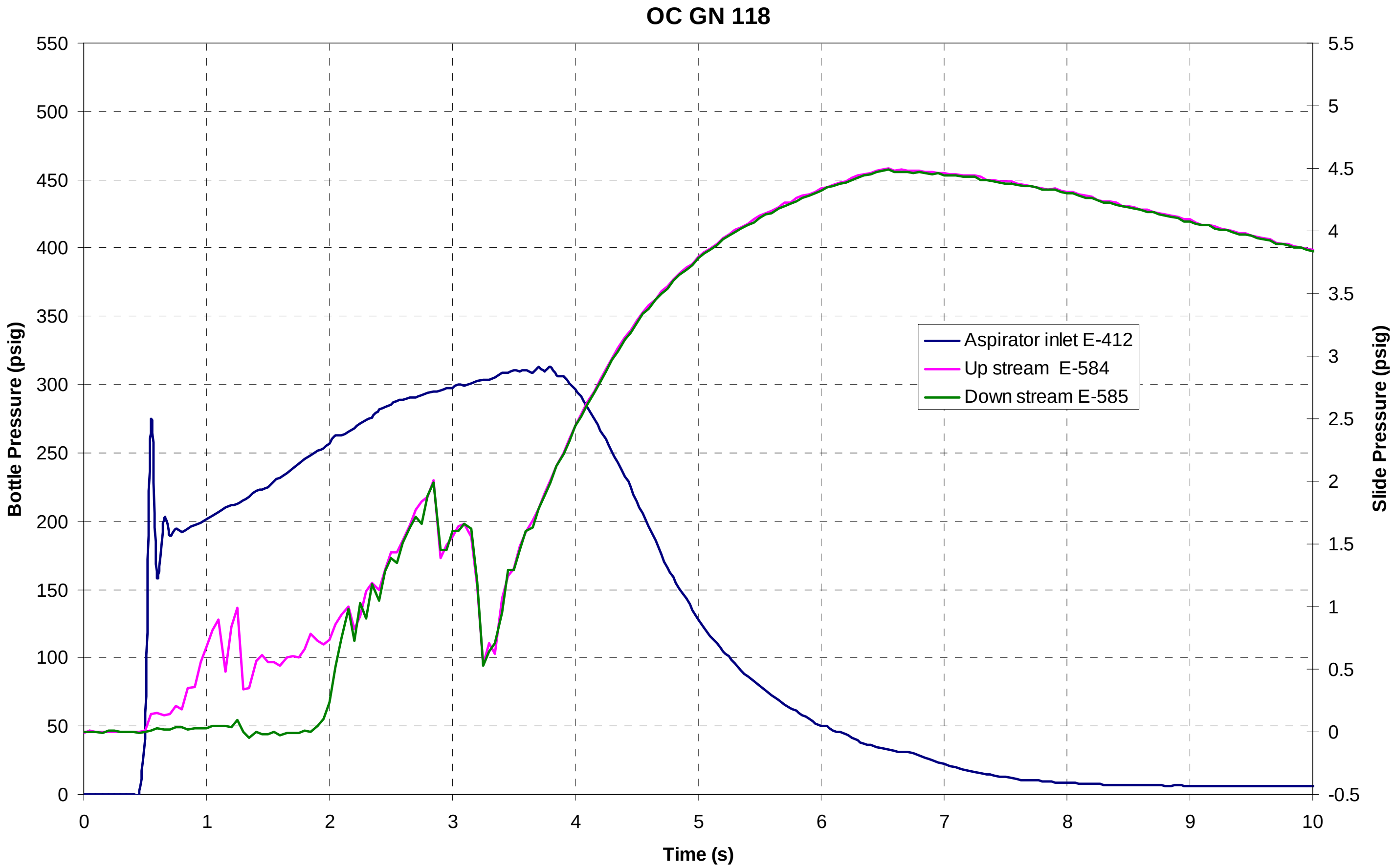
PARTIAL DEPLOYMENT – 10 000 ft (3048 m)



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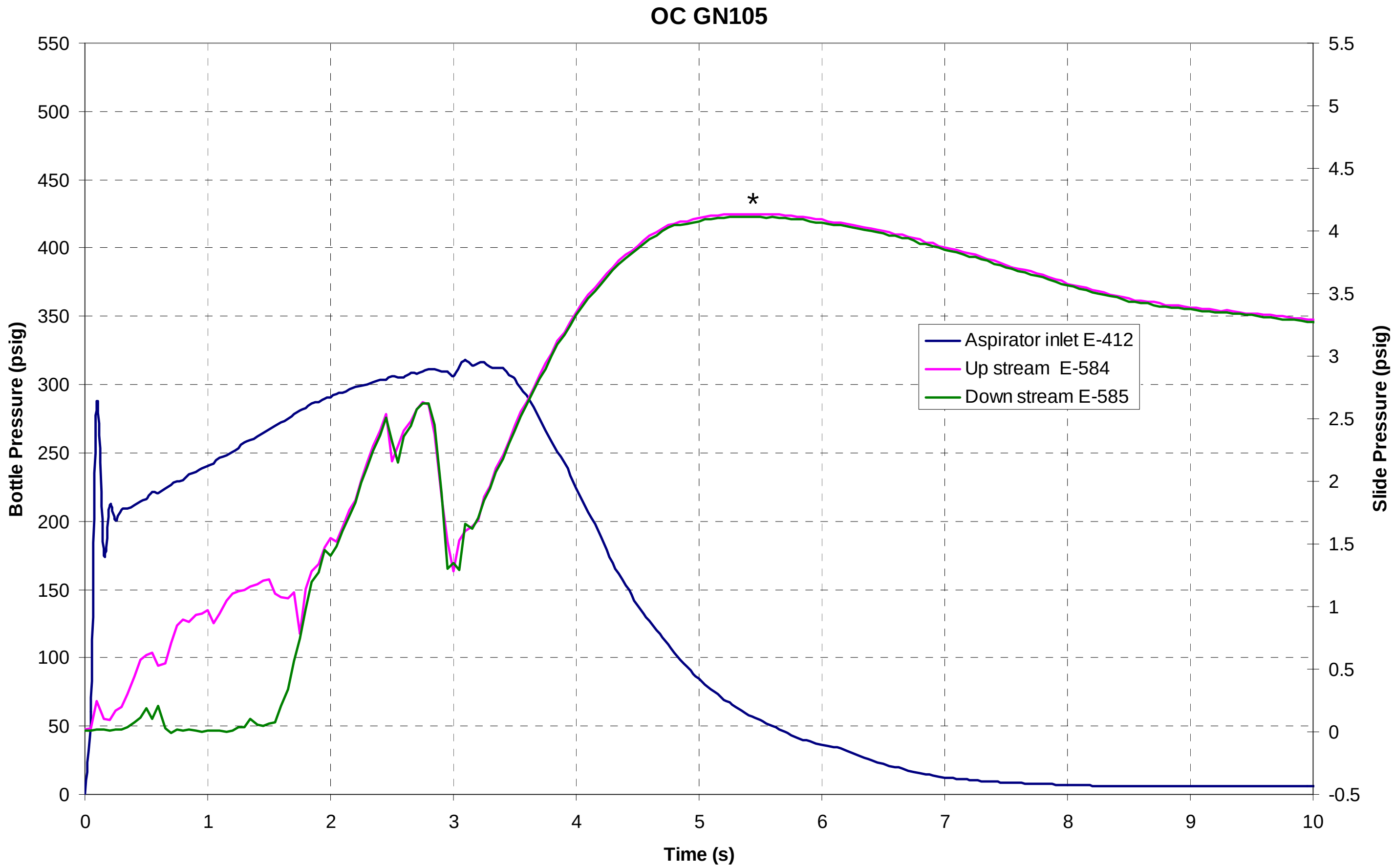
PARTIAL DEPLOYMENT – 15 000 ft (4572 m)



*Hole in tube on deployment due to contact with chamber equipment reduced peak pressure

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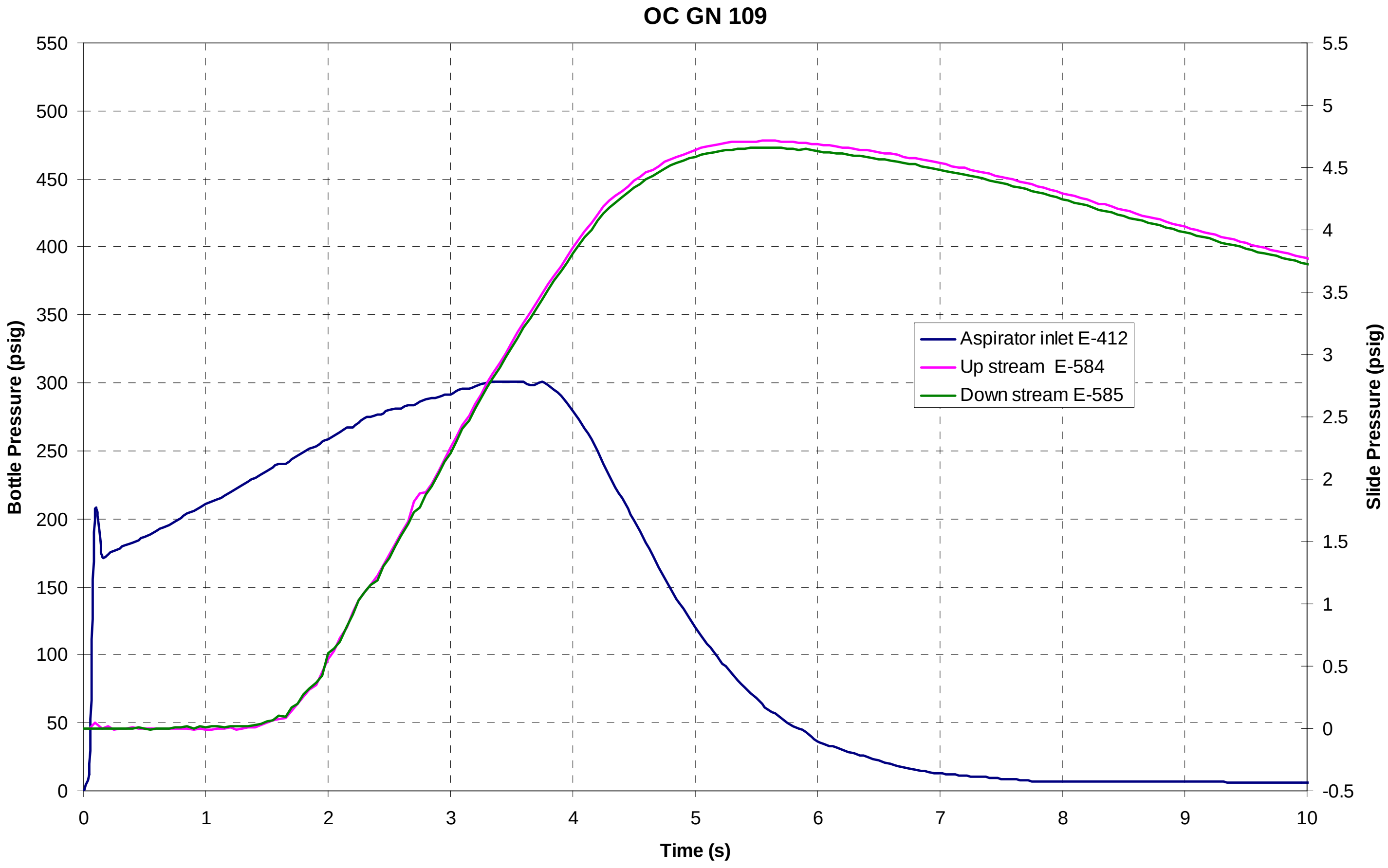
FLAT FIRE – TEST SITE



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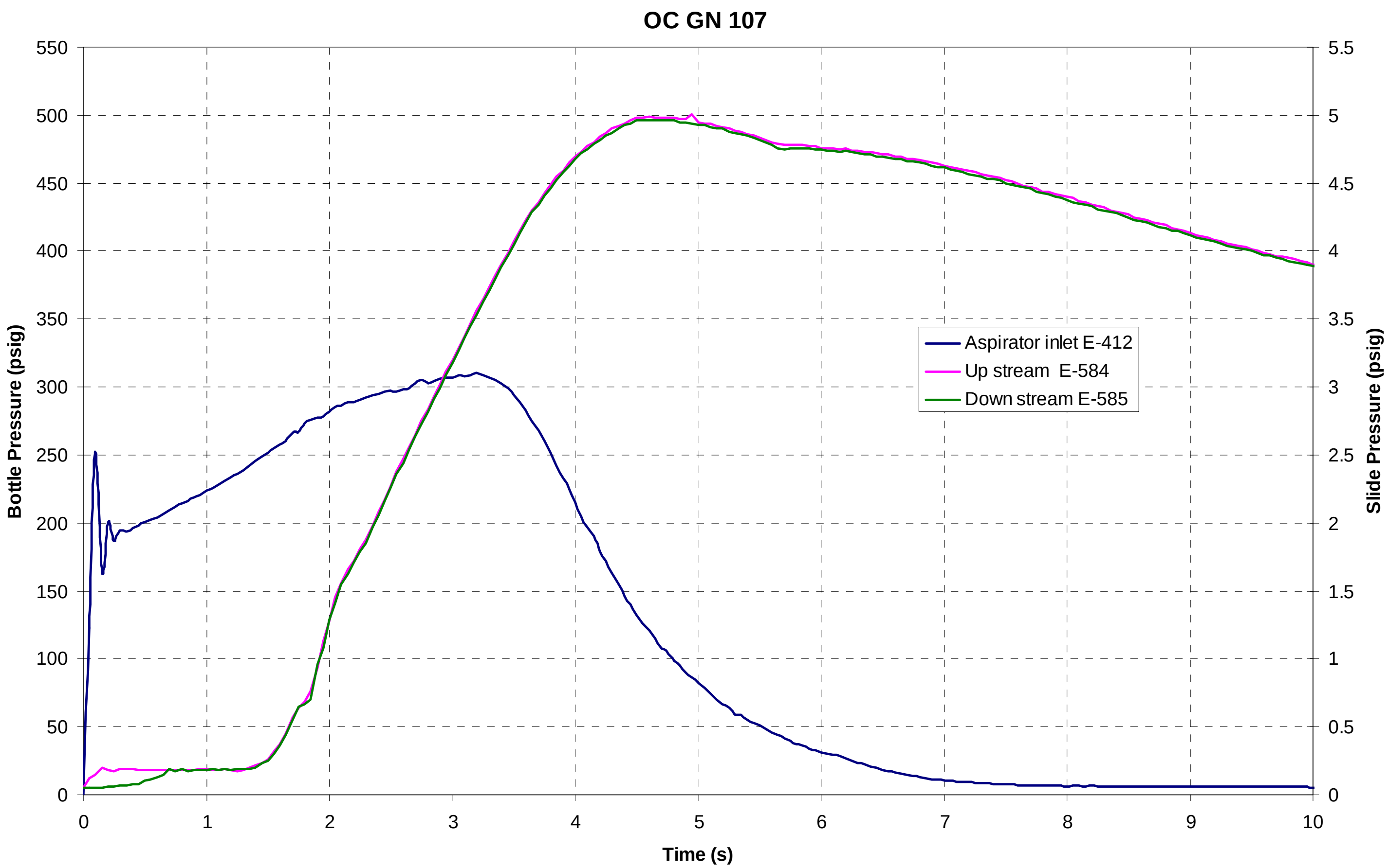
FLAT FIRE – 5000 ft (1524 m)



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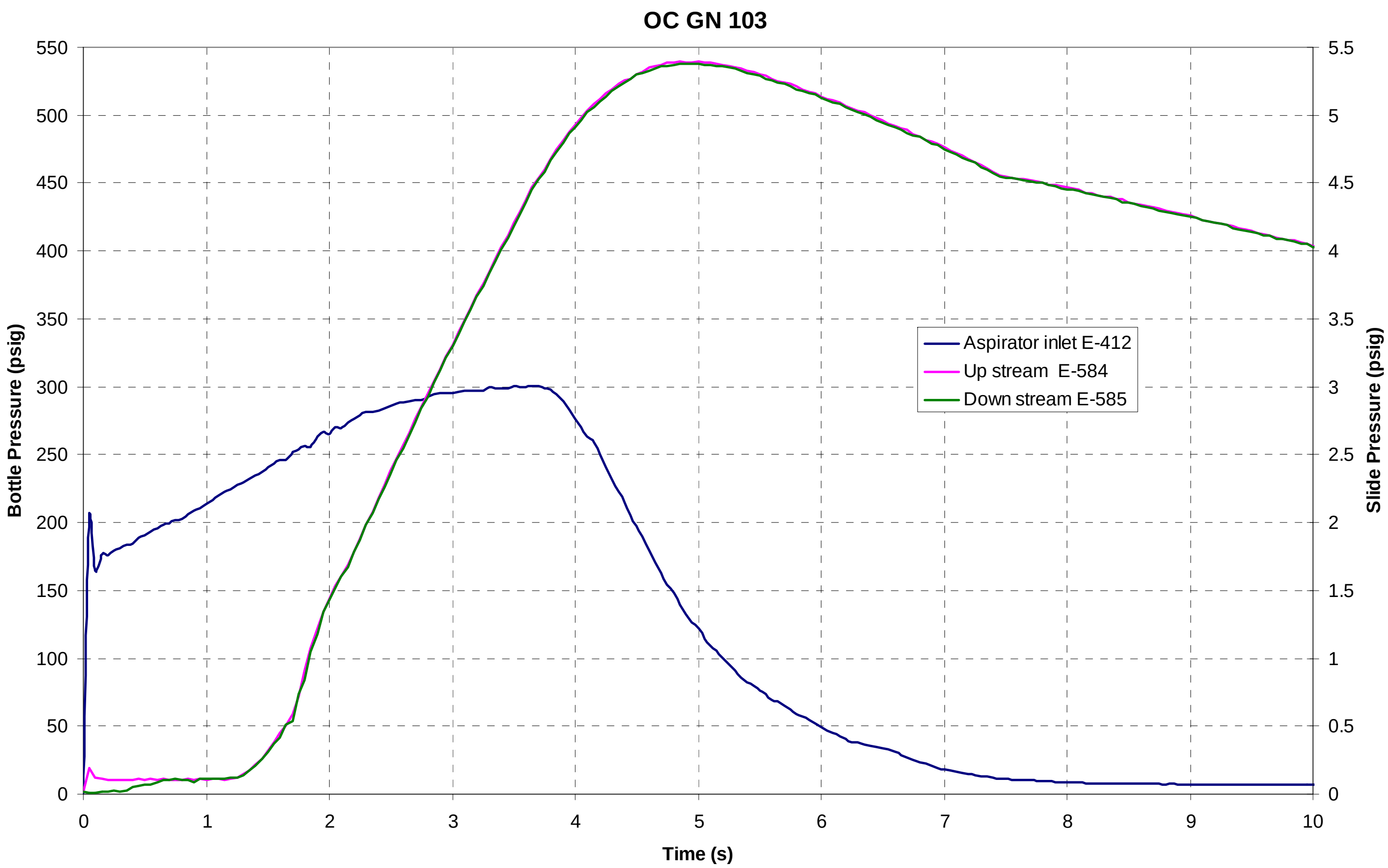
FLAT FIRE – 10 000 ft (3048 m)



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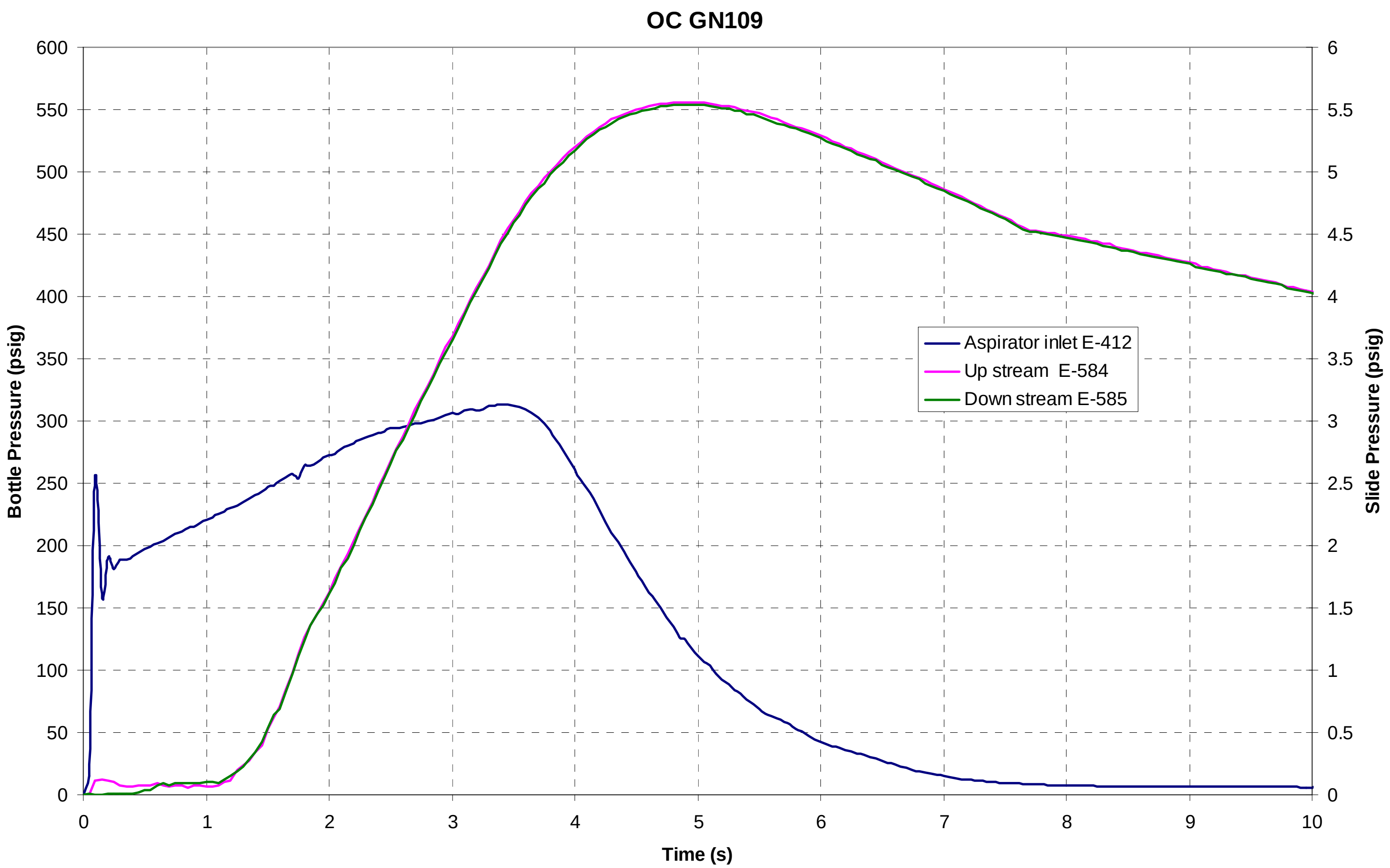
FLAT FIRE – 15 000 ft (4572 m)



SUMMARY

- Theoretical calculations based upon factory test site deployments indicated that sufficient pressure could be attained for escape slide operation at high altitudes
- Results achieved at the test altitudes indicate that indicated inflation pressures may increase with increasing altitude
- The modern escape slide assembly can inflate to an acceptable pressure for evacuation use at altitudes from sea level to 15 000 ft (4572 m)