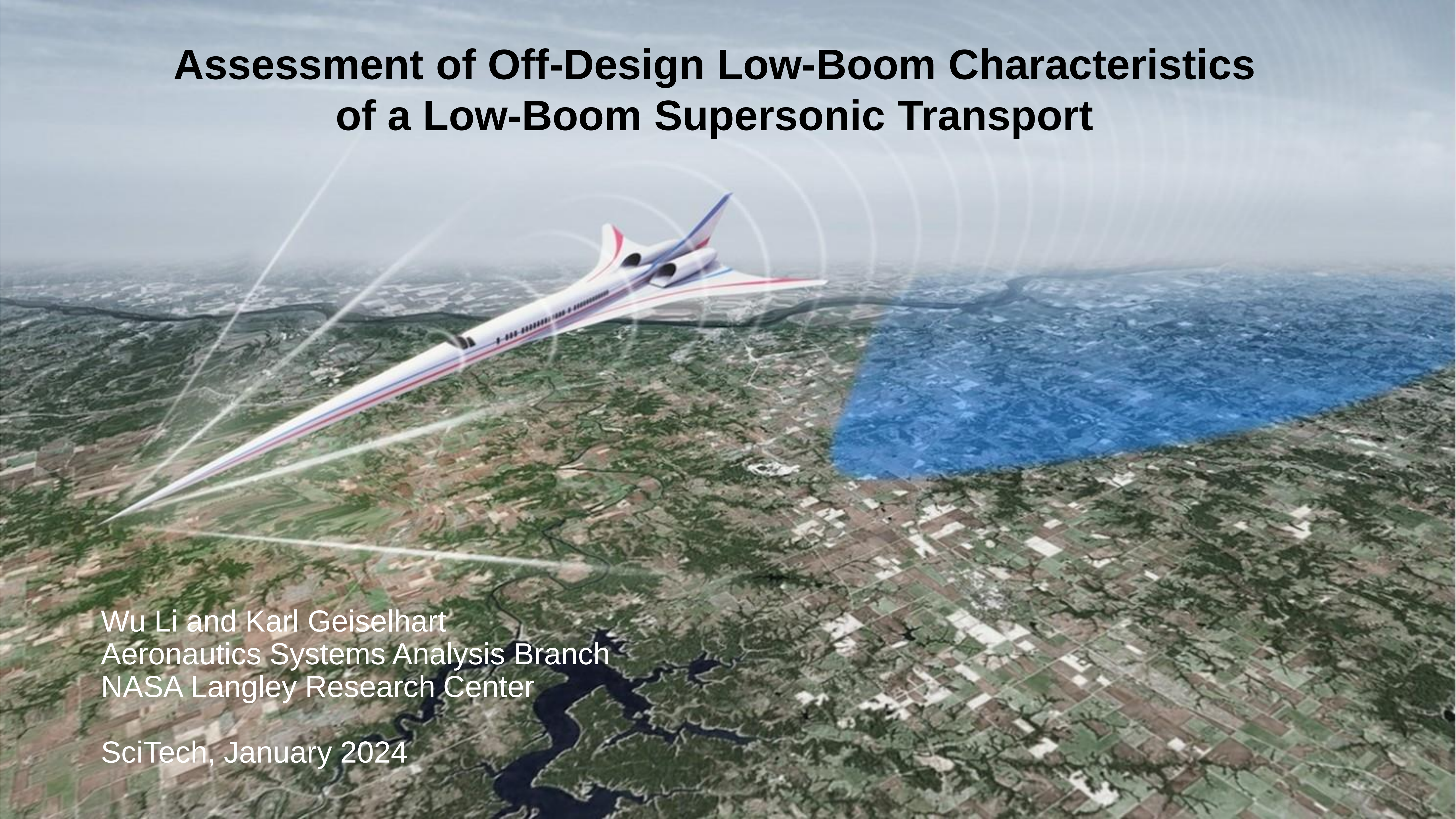

Assessment of Off-Design Low-Boom Characteristics of a Low-Boom Supersonic Transport

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Outline

- Motivation
- Minimum Requirements for Low-Boom Concepts
- Optimal Mission Profile for Low-Boom Supersonic Aircraft
- Assessment Method for Off-Design Low-Boom Characteristics
- Undertrack Low-Boom Characteristics of Low-Boom Concept
- Off-track Low-Boom Characteristics of Low-Boom Concept
- Conclusions

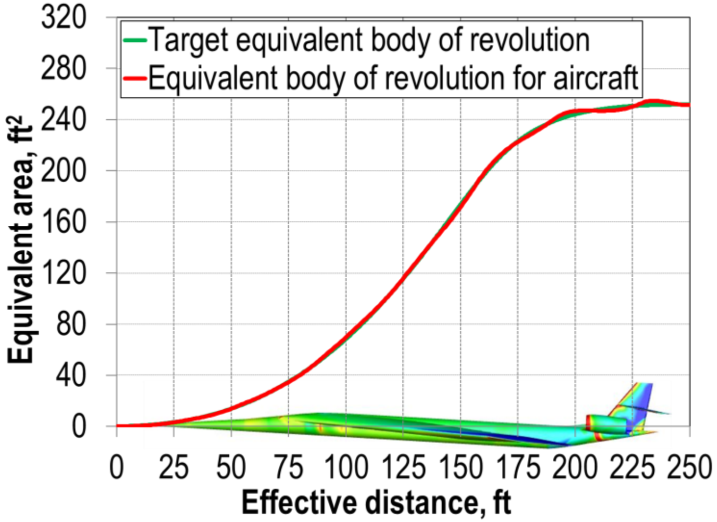
Motivation

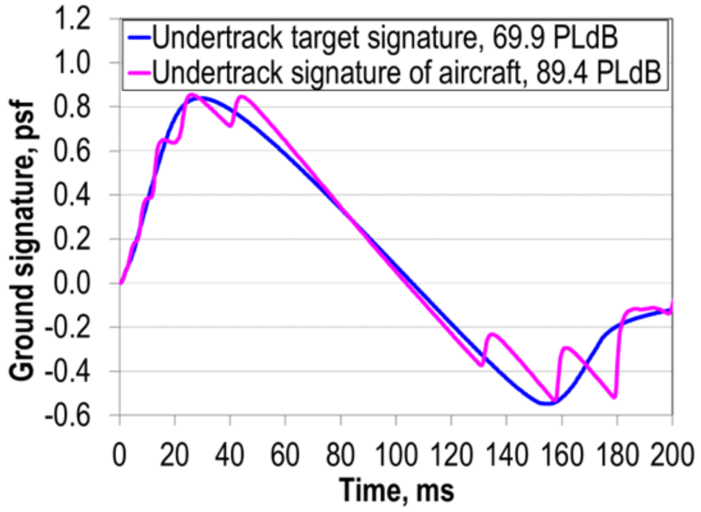
- Multiple studies indicate that the ban on overland supersonic flights has a detrimental impact on the economic viability of supersonic transports.
- NASA has been developing low-boom technologies to enable commercial supersonic overland flights, which will be demonstrated by the X-59.
- Two supersonic transport concepts with 40 passengers were successfully developed to satisfy a conceptual-level low-boom constraint and achieve the required mission performance goals. (Published in 2021 and 2022)
- How could we generate a supersonic transport concept that has the potential to have the desired low-boom characteristics over the primary boom carpet for the entire cruise segment?

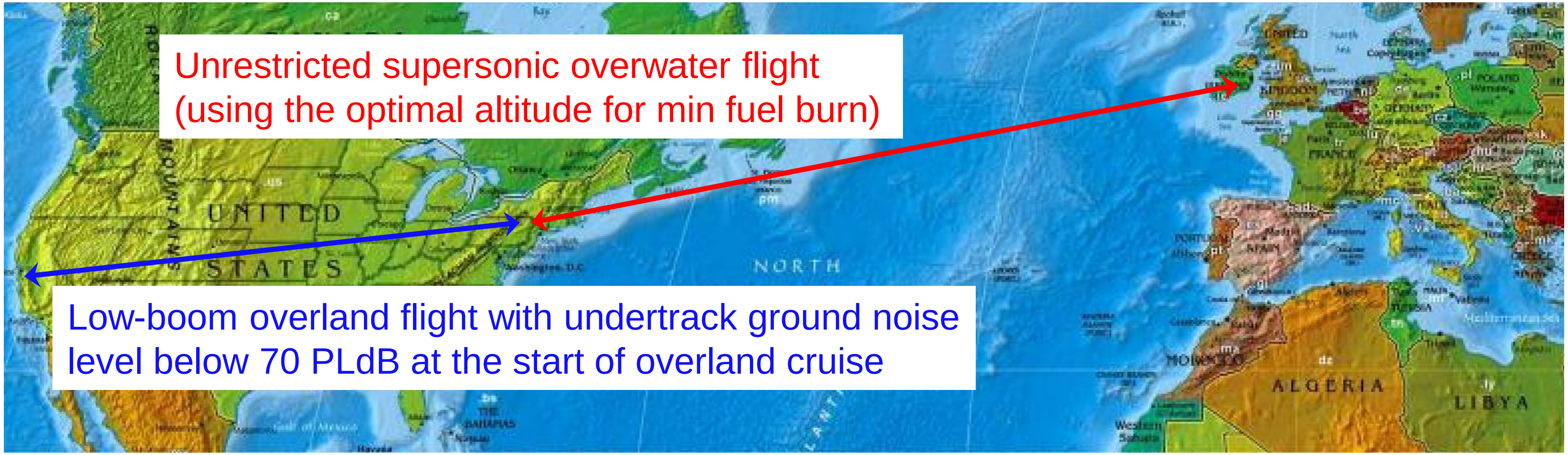
Minimum Requirements for Low-Boom Supersonic Transports

- Overwater range ≥ 3600 nm for transatlantic flights, cruise Mach 1.8
- Overland range ≥ 2500 nm for airport pairs in continental US
- Overland supersonic flight with cruise Mach ≥ 1.4 and sonic boom ground noise level below 70 PLdB (NASA N+3 goal)

Low-boom constraint at start of overland cruise

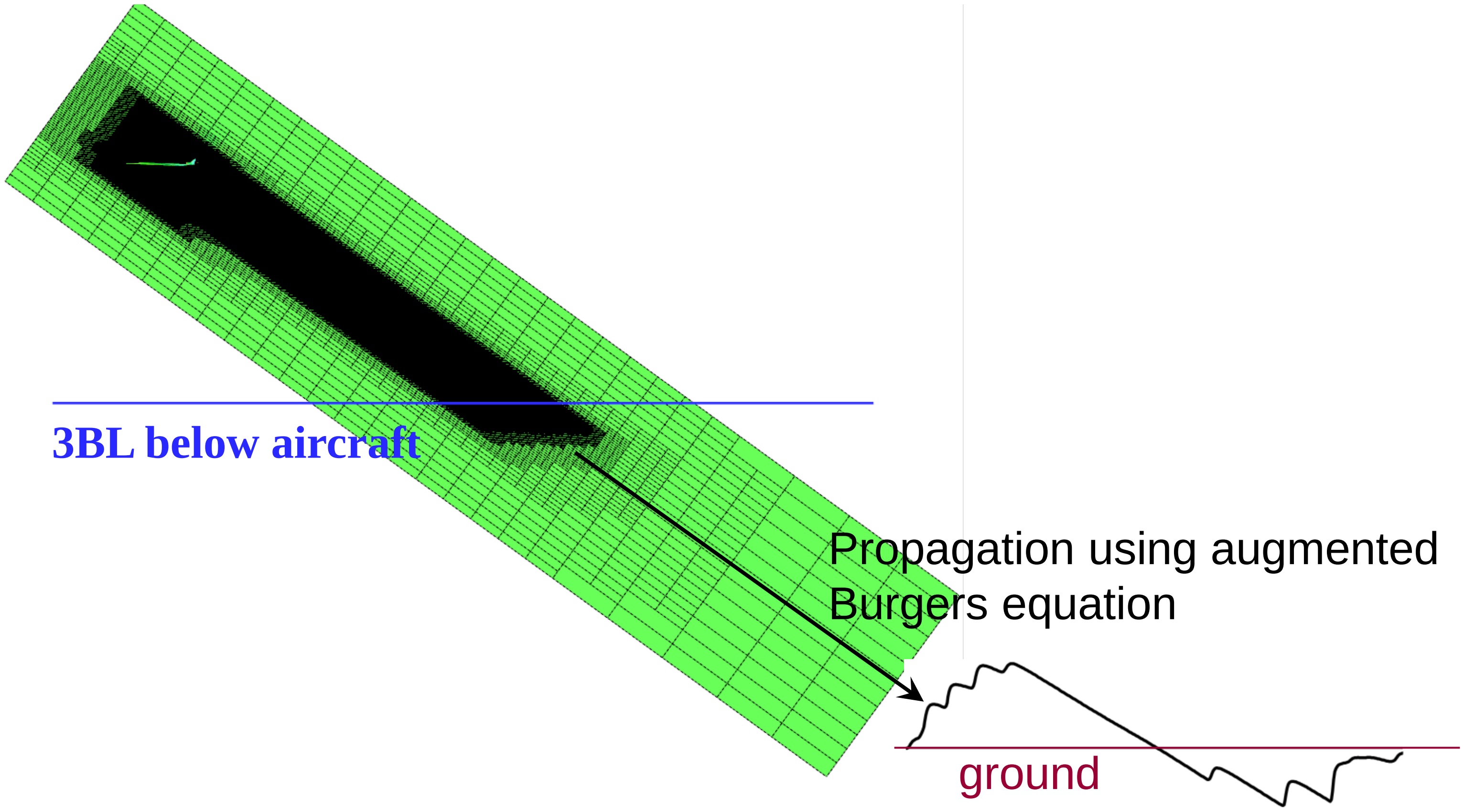






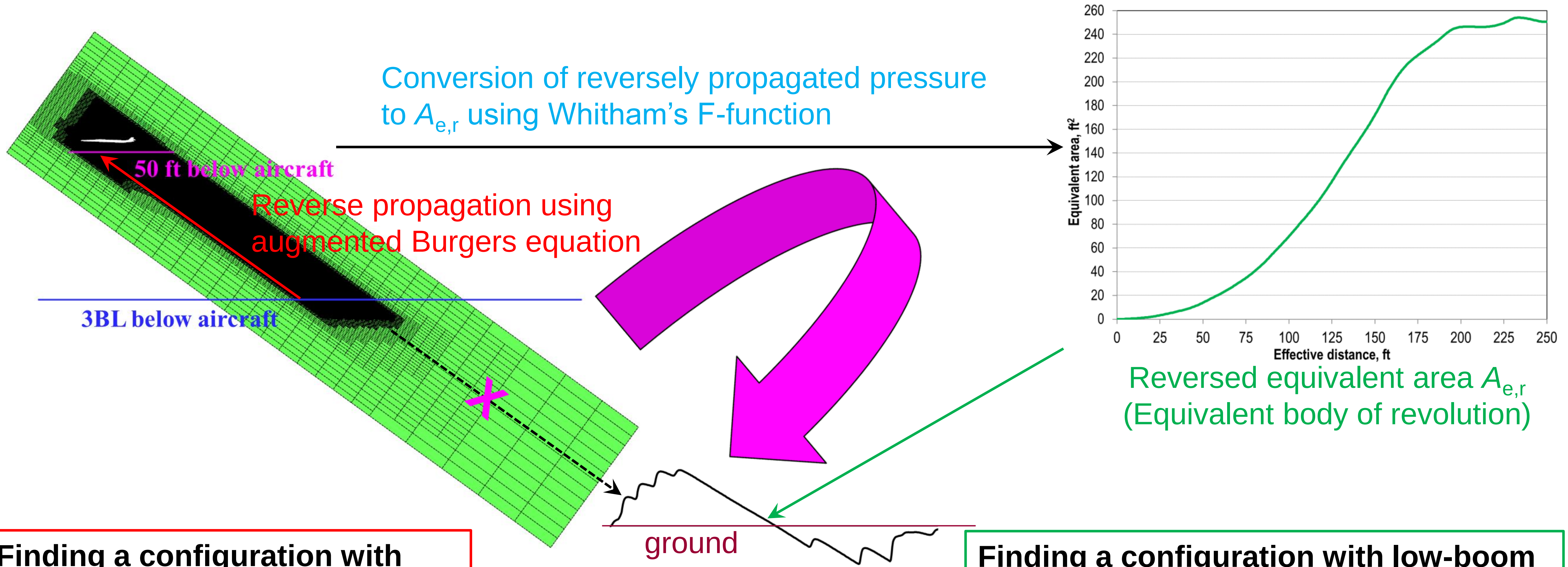
Sonic Boom Analysis Using CFD Off-Body Pressure

1. Use CFD off-body pressure at the location of 3 body lengths (3BL) below the aircraft.
2. Use an augmented Burgers equation to propagate the CFD off-body pressure through the atmosphere to the ground.
3. Compute the perceived level of decibels (PLdB) of the ground signature.



Sonic Boom Analysis Using Reversed Equivalent Area

1. Reversely propagate the off-body pressure to 50 ft below the aircraft.
2. Convert the reversely propagated pressure to equivalent area.
3. Propagate the equivalent area to the ground and compute its PLdB value.

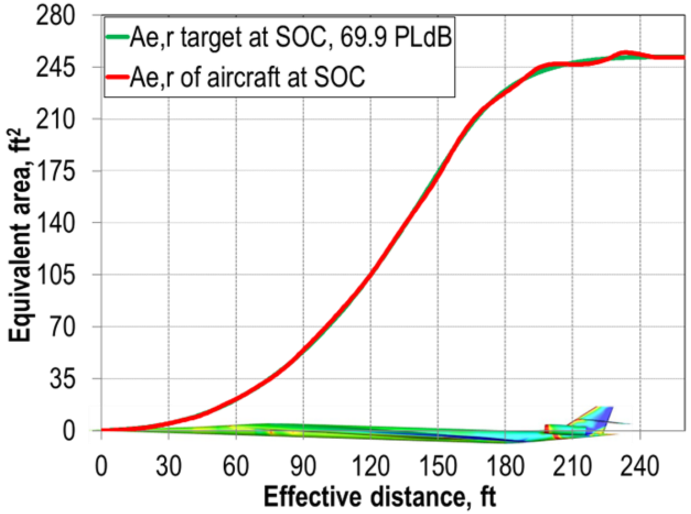


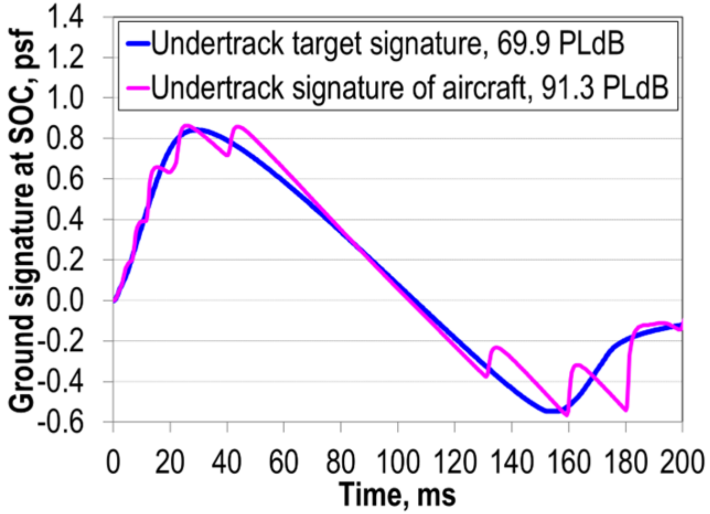
Finding a configuration with low-boom undertrack signature

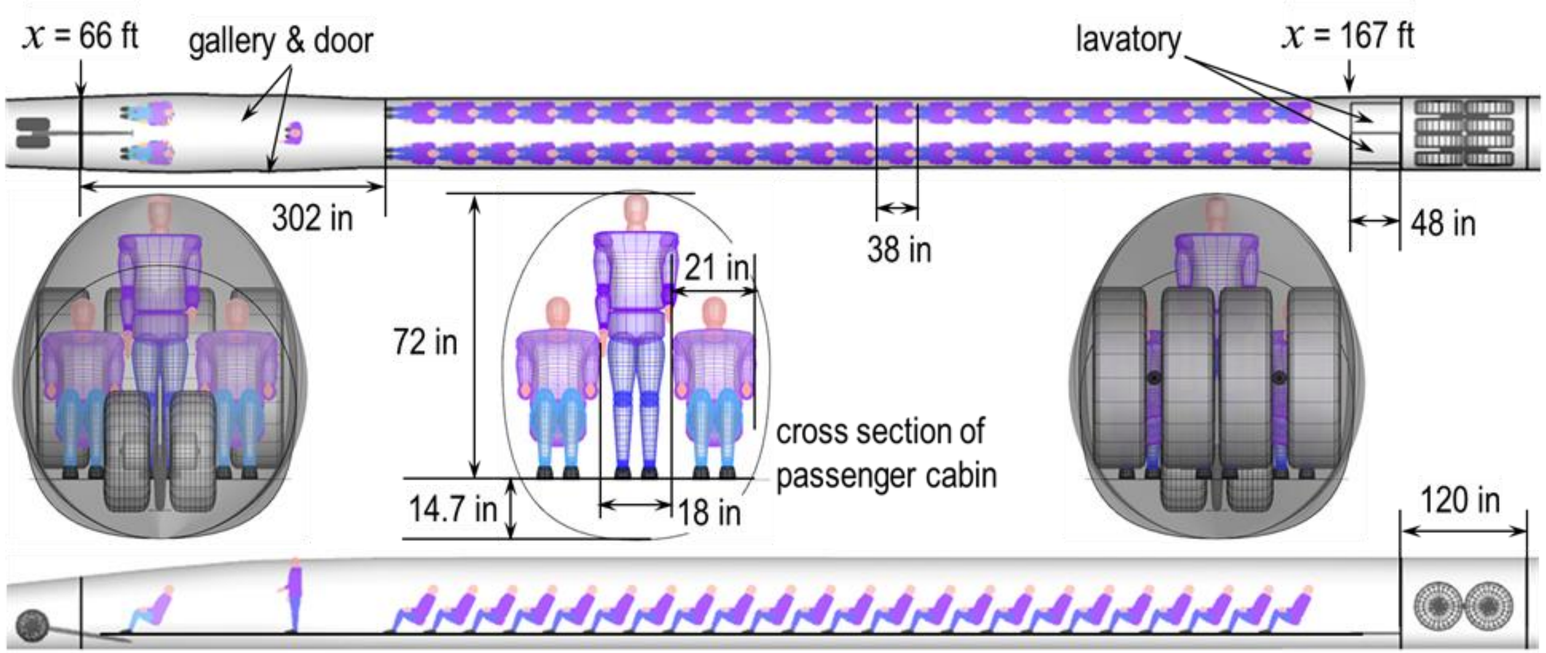
Finding a configuration with low-boom shape for the reversed equivalent area

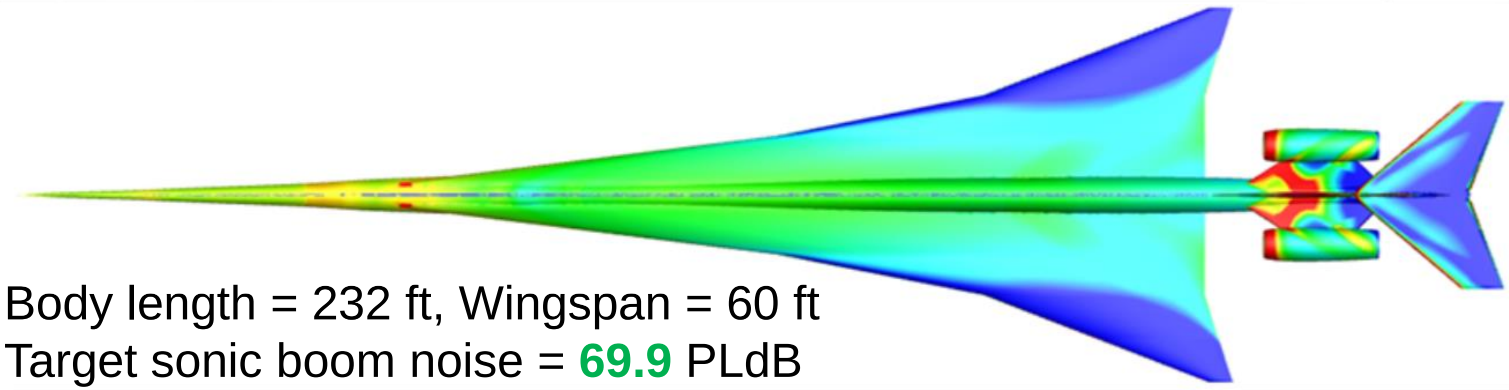
Low-Boom Concept at Start of Overland Cruise (SOC)

Concept	Passenger No.	MTOGW	OL Mach	OL Range	OW Mach	OW Range
46-PAX	46	147,600 lb	1.7	3317 nm	1.8	3671 nm









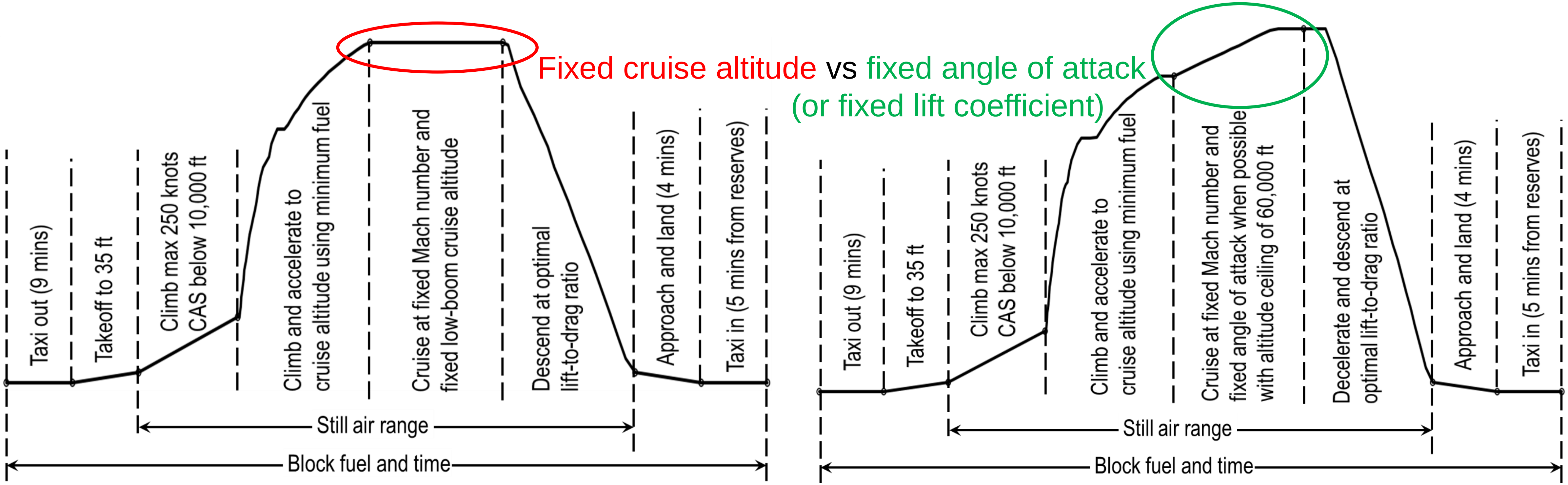
Body length = 232 ft, Wingspan = 60 ft

Target sonic boom noise = **69.9** PLdB

Optimal Mission Profile for Low-Boom Supersonic Concept

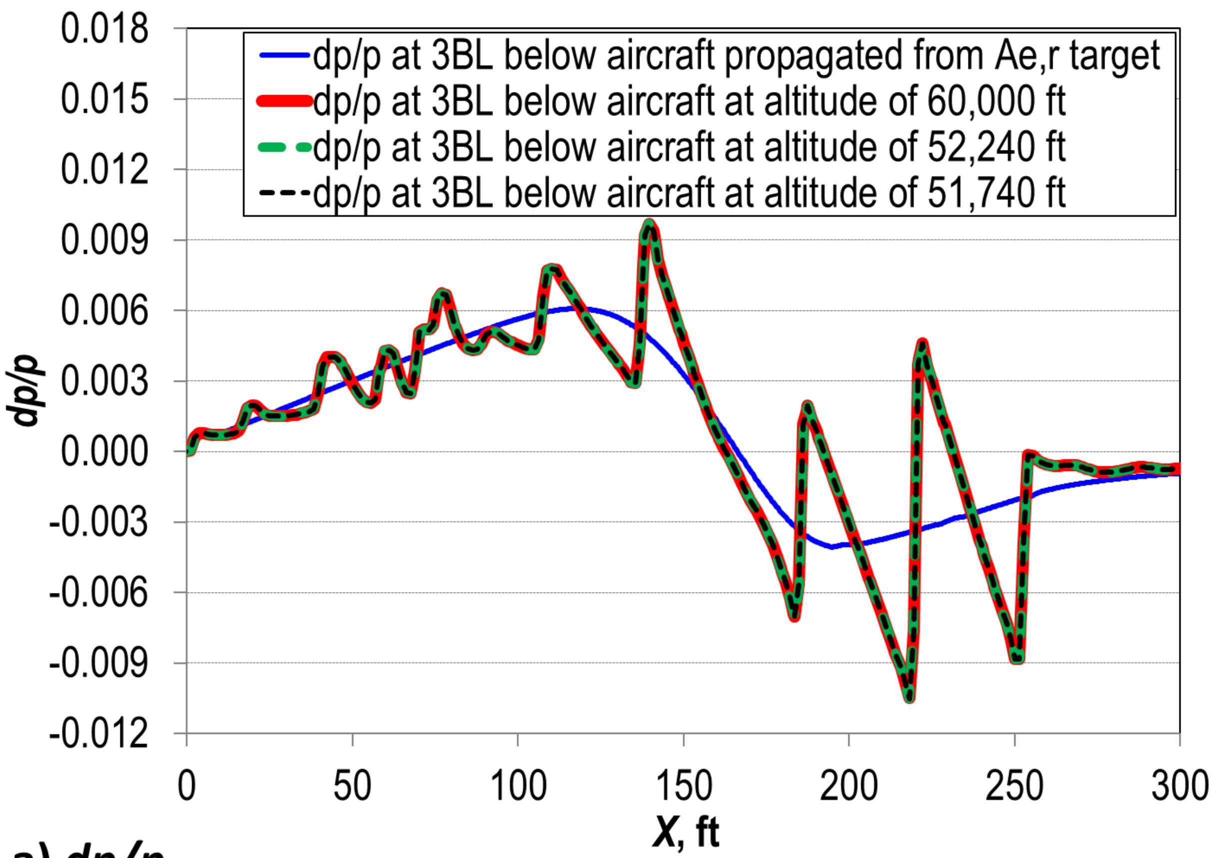
Two advantages of the low-boom mission profile with fixed angle of attack for cruise:

- Easier to retain the designed low-boom characteristics at the start of cruise.
- Better fuel efficiency for cruise.

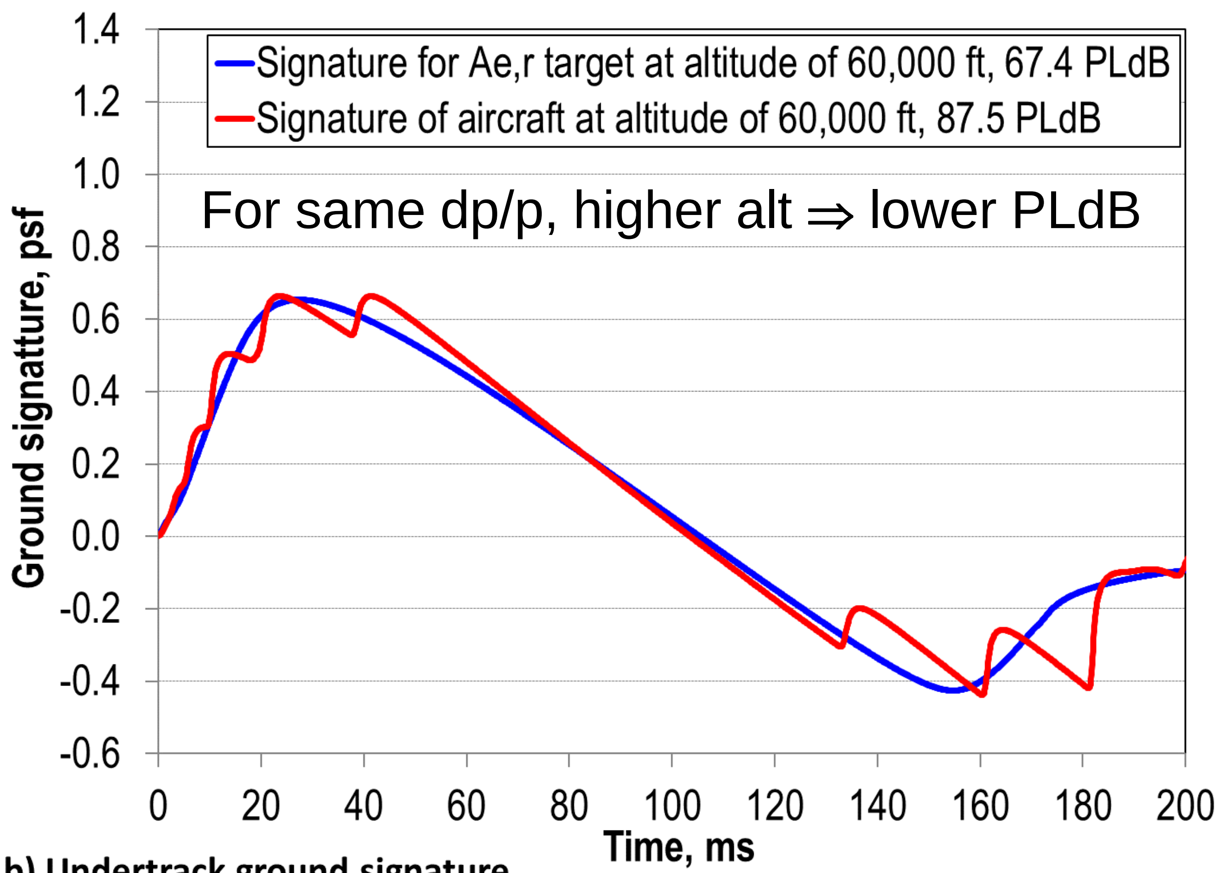


Benefits of Optimal Mission Profile for Low-Boom Concept

OL Cruise Constraint	Passenger No.	MTOGW	OL Mach	OL Range	OW Mach	OW Range
Fixed Altitude	46	147,600 lb	1.7	3317 nm	1.8	3671 nm
Fixed AoA	46	147,600 lb	1.7	3725 nm	1.8	3671 nm



a) *dp/p*



b) Undertrack ground signature

Assessment of Off-Design Low-Boom Characteristics

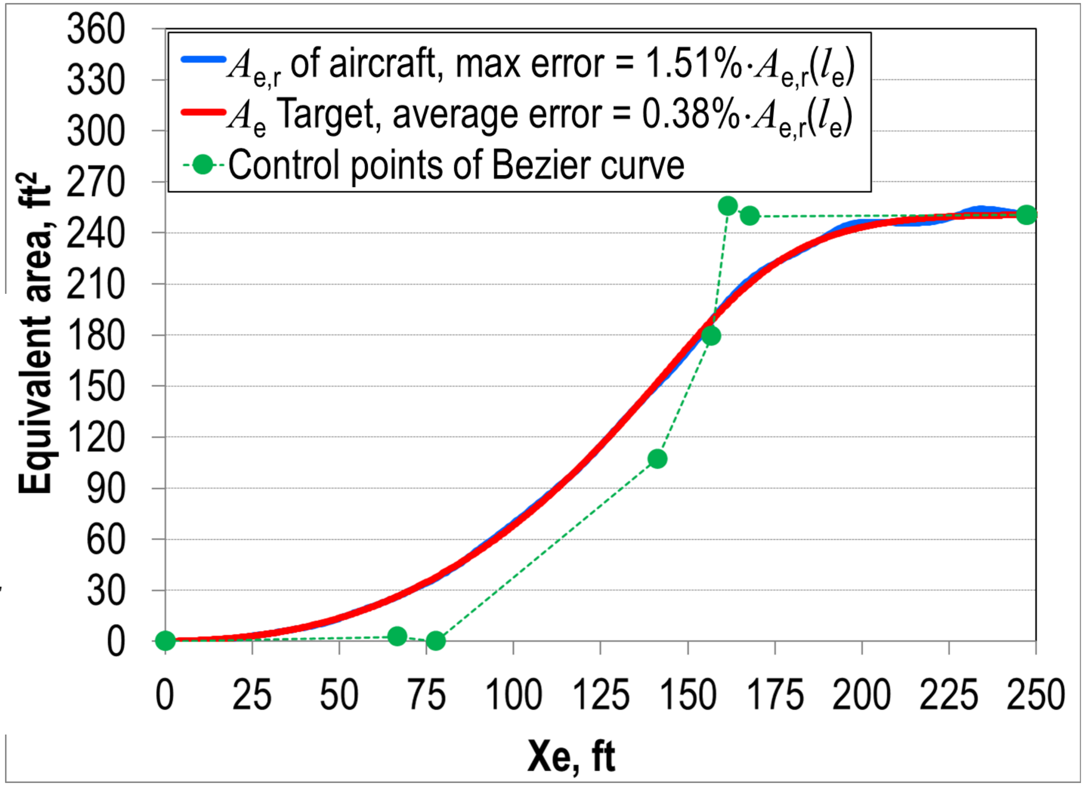
Find an equivalent area target with the lowest PLdB value while having an acceptable inverse design error.

$$\min_{\boldsymbol{d}} \mathrm{PLdB}[A_\mathrm{e}(\theta)] \text{ subject to } \begin{cases} \left\| A_\mathrm{e}(\theta) - A_\mathrm{e,r}(\theta) \right\| \leq \epsilon & \text{(acceptable inverse design)} \\ A_e(0) = A_e'(0) = A_e'(l_e) = 0 & \text{(Whitham's theory)} \end{cases}$$

The design vector ***d*** consists of coordinates of control points of a Bezier curve as a parametric form of A_e.

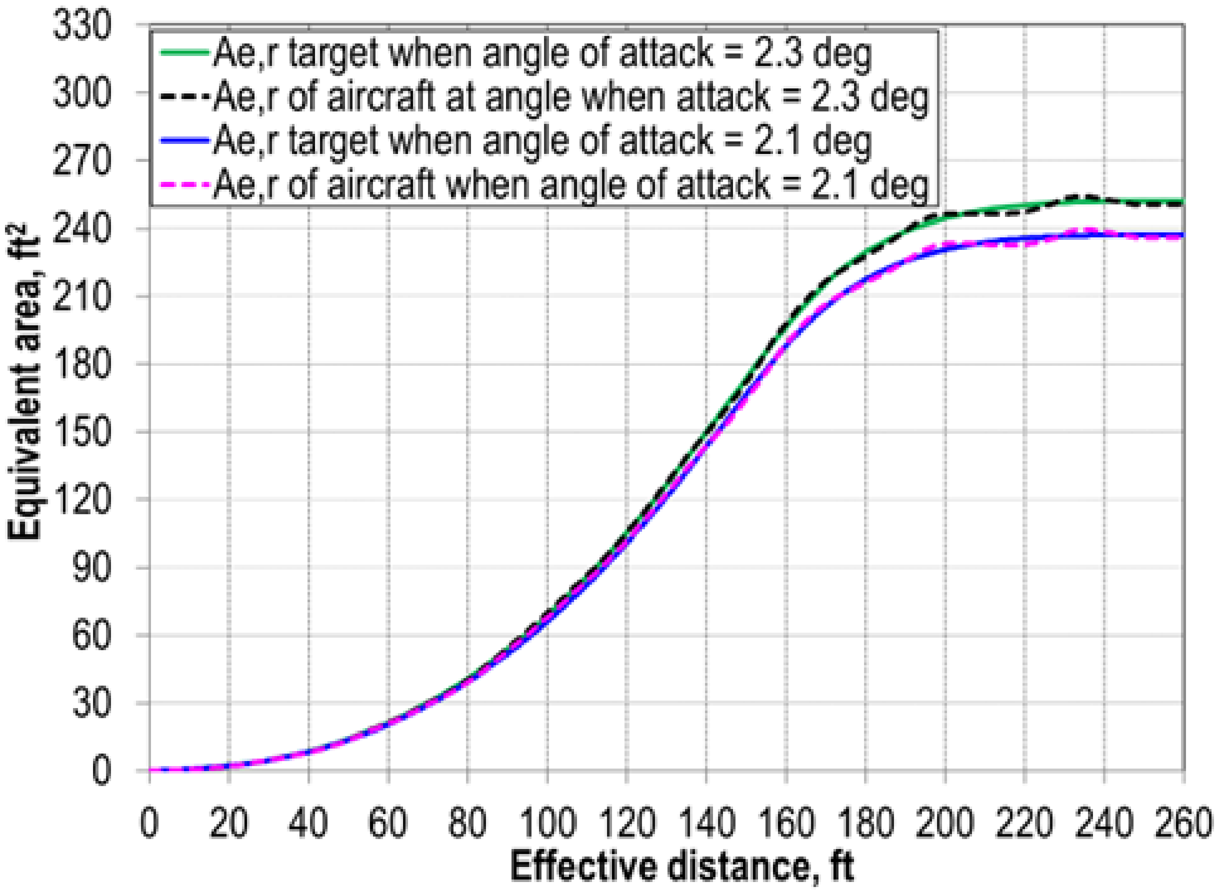
$$x(t) = l_e \cdot t^9 + \sum_{j=1}^{8} x_{c,j} \cdot \frac{9!}{j!\,(9-j)!} \cdot t^j \cdot (1-t)^{9-j}$$

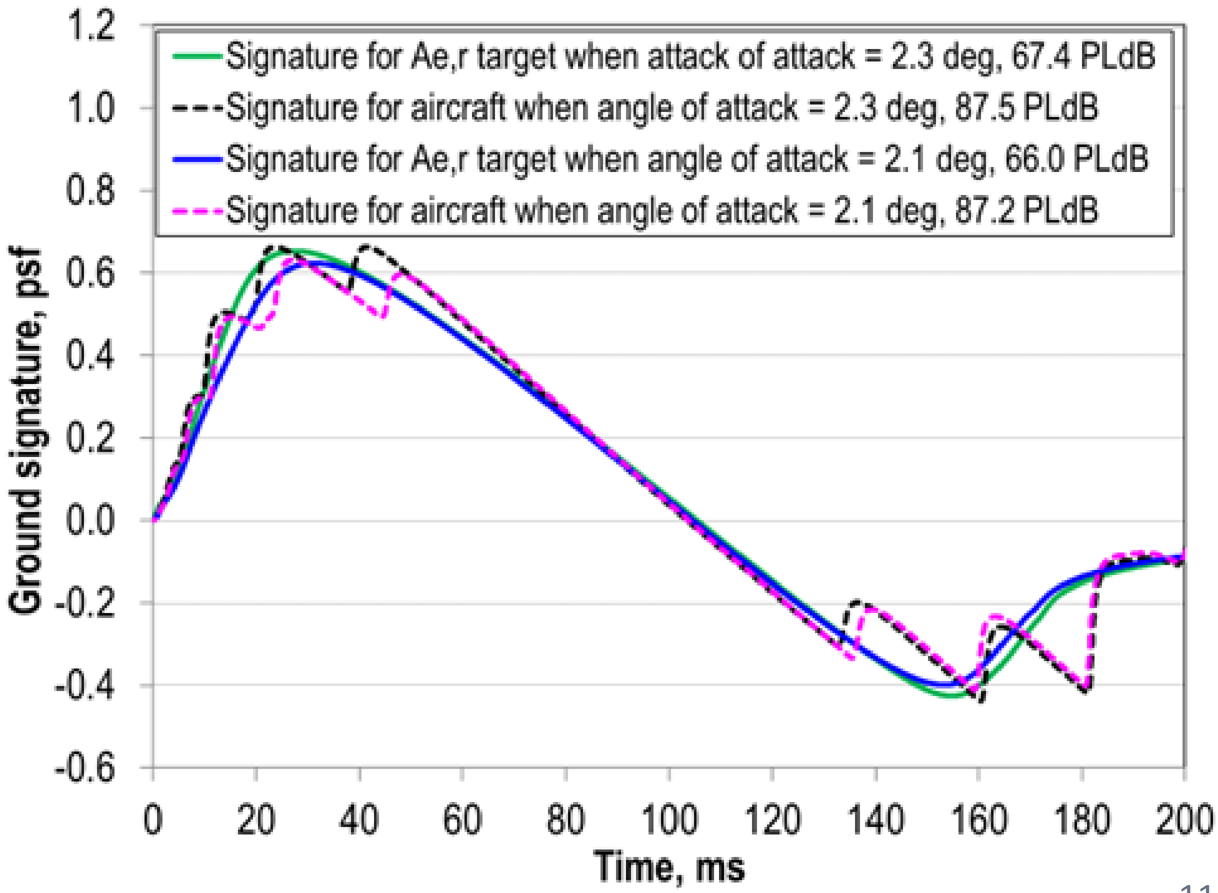
$$A_\mathrm{e}\big(x(t)\big) = y_{c,8} \cdot t^9 + \sum_{j=2}^{8} y_{c,j} \cdot \frac{9!}{j!\,(9-j)!} \cdot t^j \cdot (1-t)^{9-j}$$



Undertrack Low-Boom Characteristics for Cruise Segment

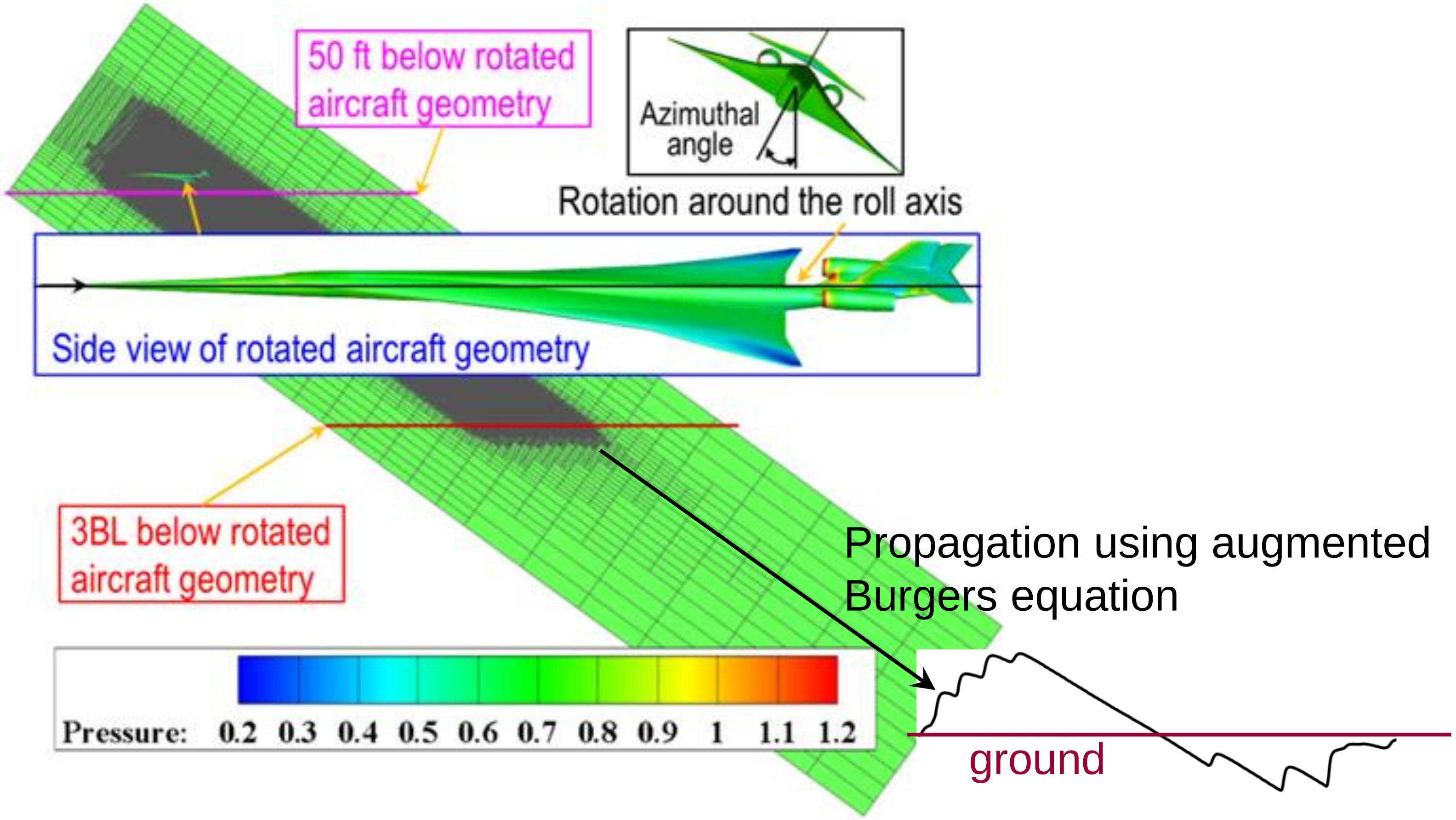
For the 46-PAX concept, the low-boom characteristics at the end of low-boom cruise are better than those at SOC. This is due to the reduced cruise weight and increased cruise altitude.

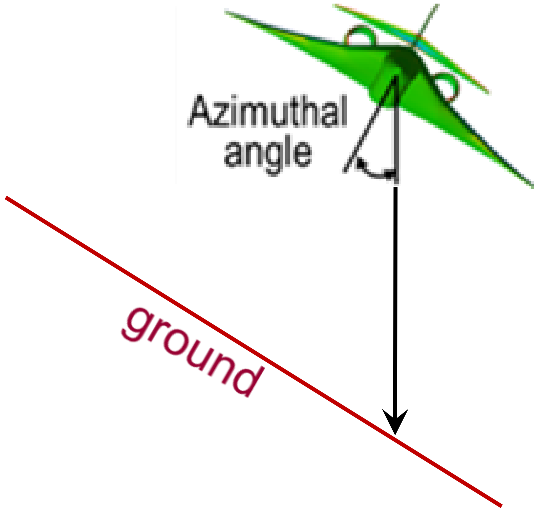




Off-Track Sonic Boom Analysis

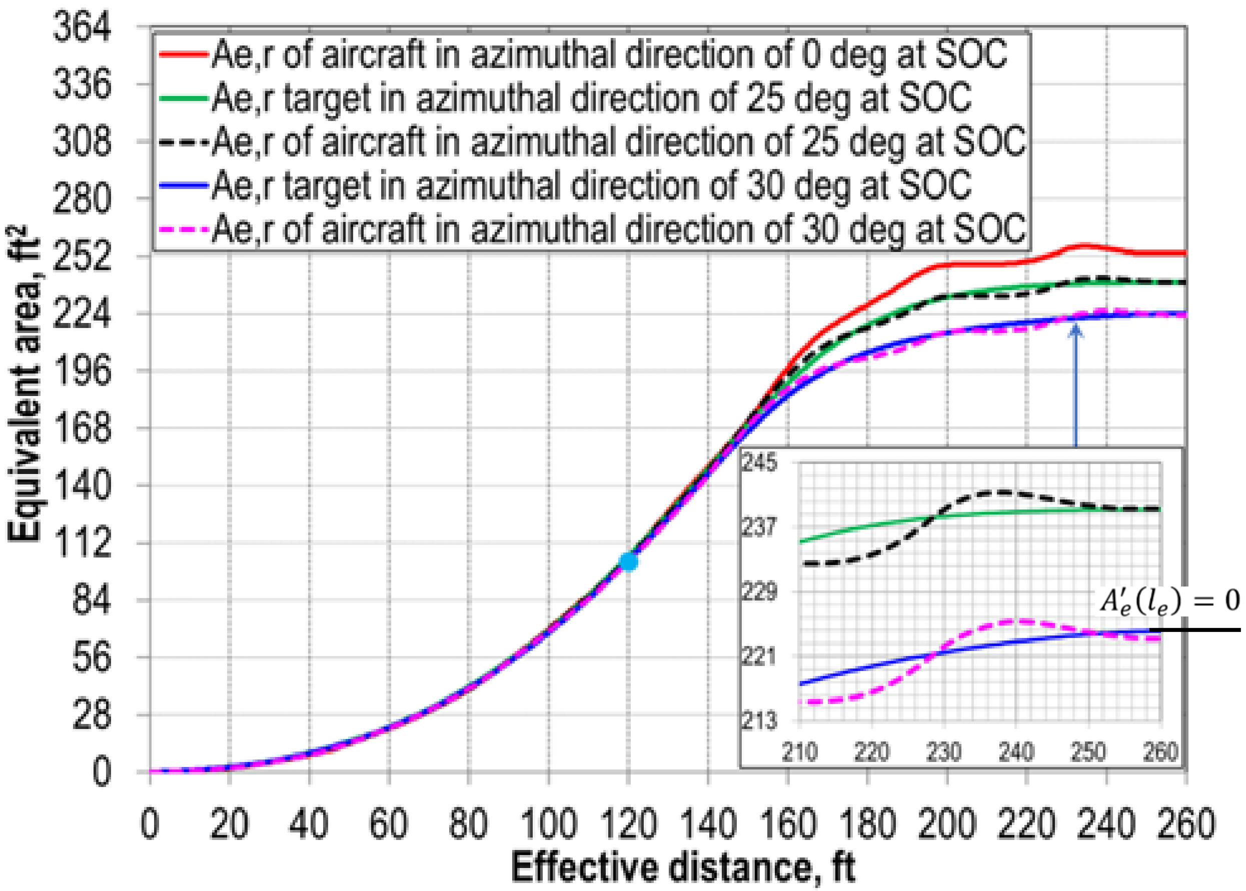
1. Use CFD off-body pressure at the location of 3BL below the **rotated** aircraft.
2. Use an augmented Burgers equation to propagate the CFD off-body pressure along the azimuthal direction through the atmosphere to the ground.
3. Compute the perceived level of decibels (PLdB) of the ground signature.

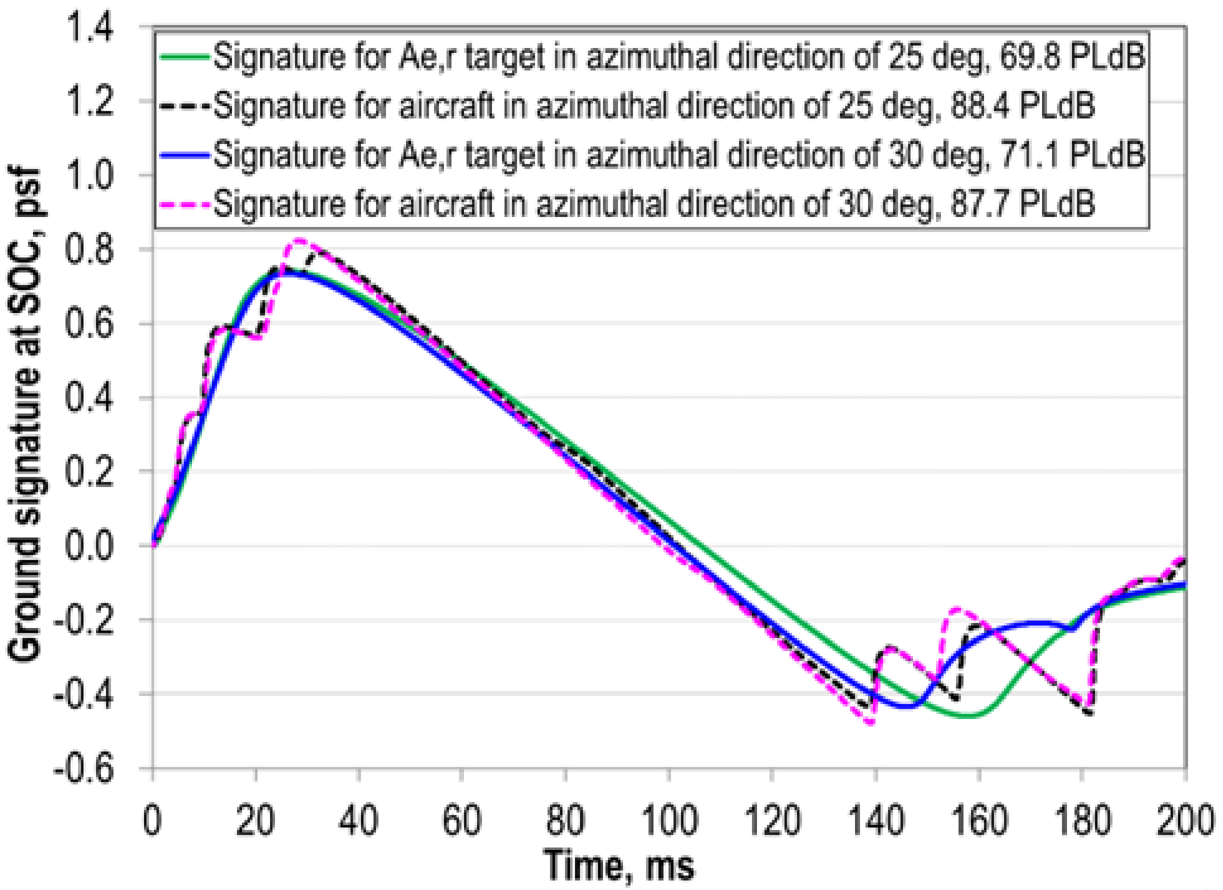




Off-Track Low-Boom Characteristics at Start of Cruise (I)

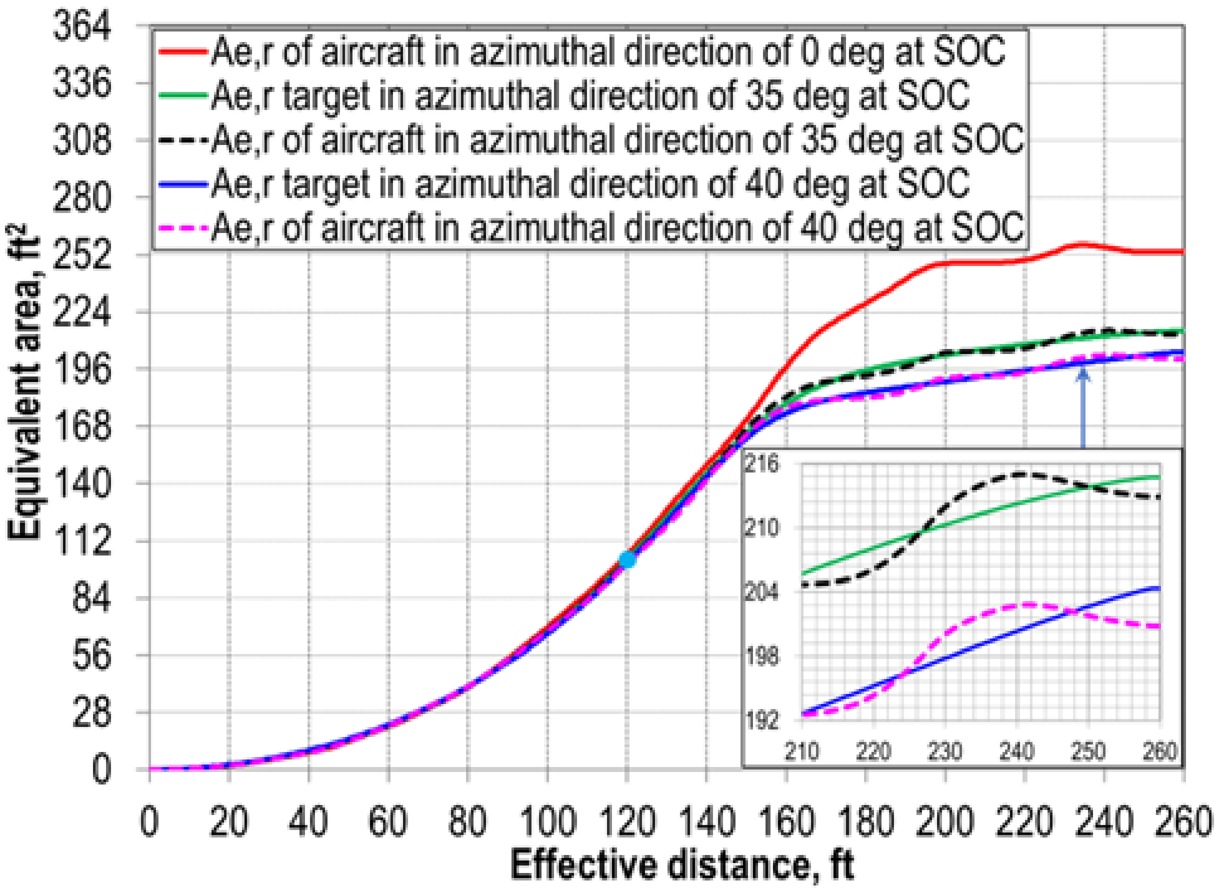
- The 46-PAX concept behaves like a body of revolution for effective distance < 120 ft.
- The aft low-boom characteristics starts to deteriorate for off-track angle = 30 deg.

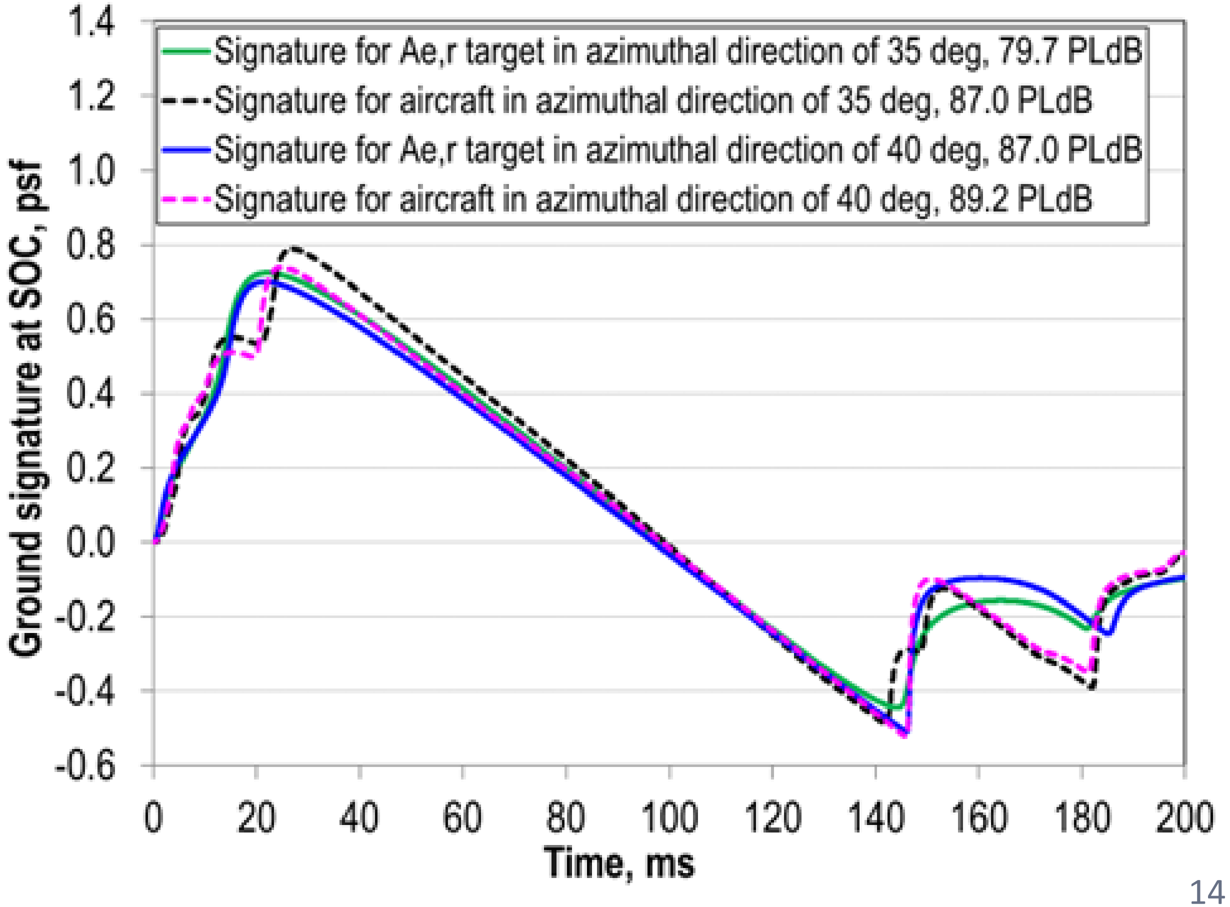




Off-Track Low-Boom Characteristics at Start of Cruise (II)

- The 46-PAX concept behaves like a body of revolution for effective distance < 120 ft.
- The aft shape of the equivalent area target has an almost linear area increase for off-track angle ≥ 35 deg.





Conclusions

- This work suggests that within the low-boom design space, there exist configurations capable of retaining favorable low-boom characteristics throughout cruise, while maintaining a constant-CL cruise state that maximizes range.
- The analysis method for assessment of off-design low-boom characteristics can be used to screen out supersonic configurations not feasible for robust low-boom design over the primary boom carpet for the entire cruise segment.

Acknowledgement

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