Reducing Sonic Boom Strength by Tailoring the Propulsive Streamtube

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AIAA Aviation and Aeronautics Forum
Atlanta, Georgia
June 16-20, 2014

Presented previously at the
2013 AIAA Propulsion and Energy Forum
See paper AIAA-2013-3678

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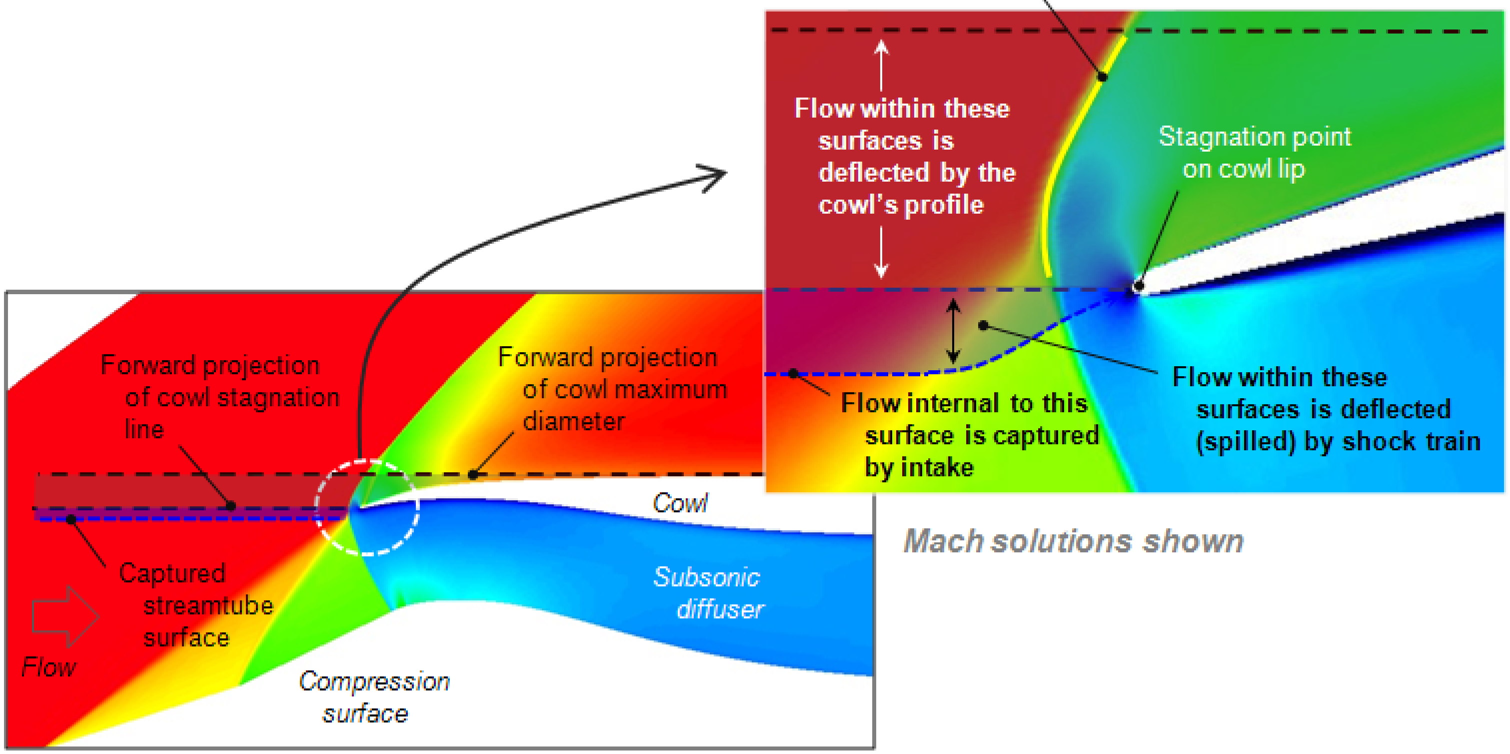
Supersonic External Flow Deflection for a Traditional Inlet

The strength of the escaping shock feature correlates to the quantity of flow deflected and the axial spatial gradient over which it occurs



Mach solutions shown

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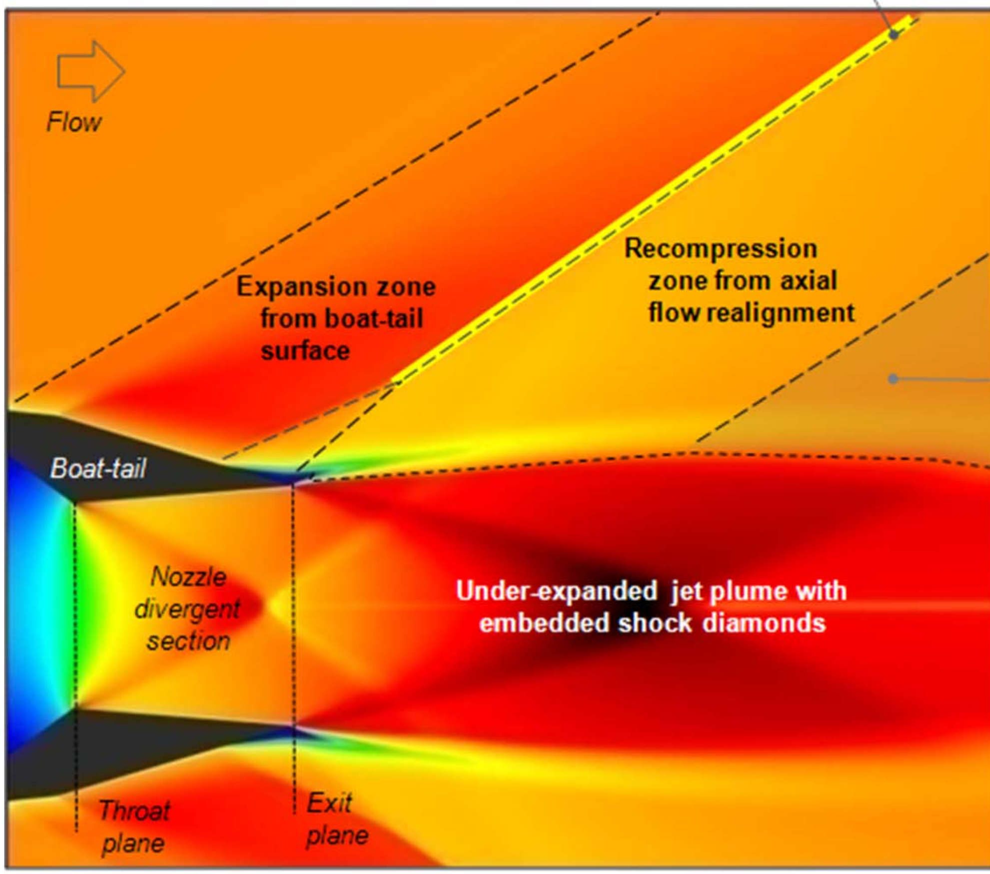
Supersonic External Flow Deflection for a Traditional Nozzle

The strength of the escaping shock feature correlates to the nacelle's boat-tail angle and the spatial gradient over which axial flow realignment occurs



Mach solution shown

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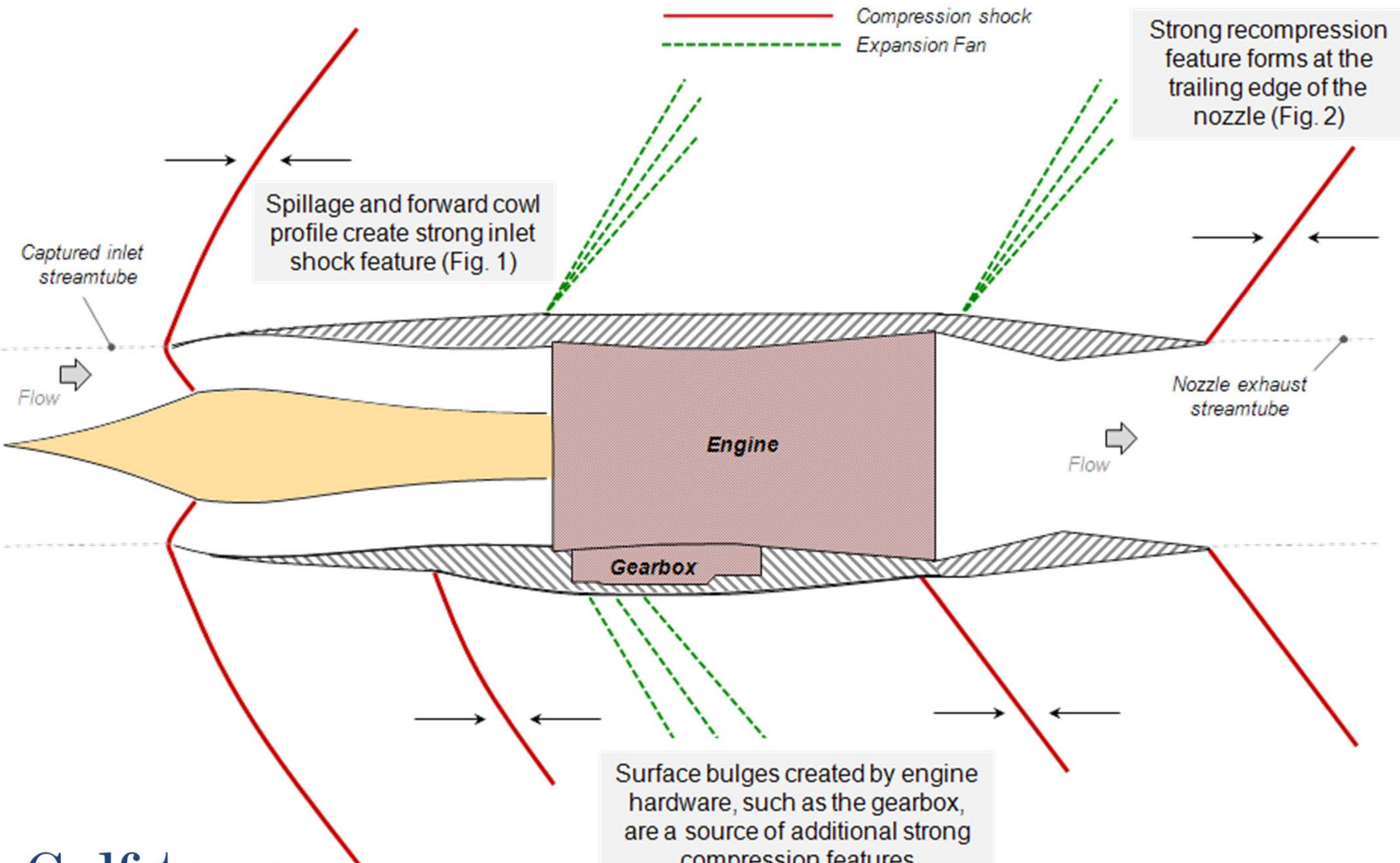
Compression Features Created by a Traditional Nacelle



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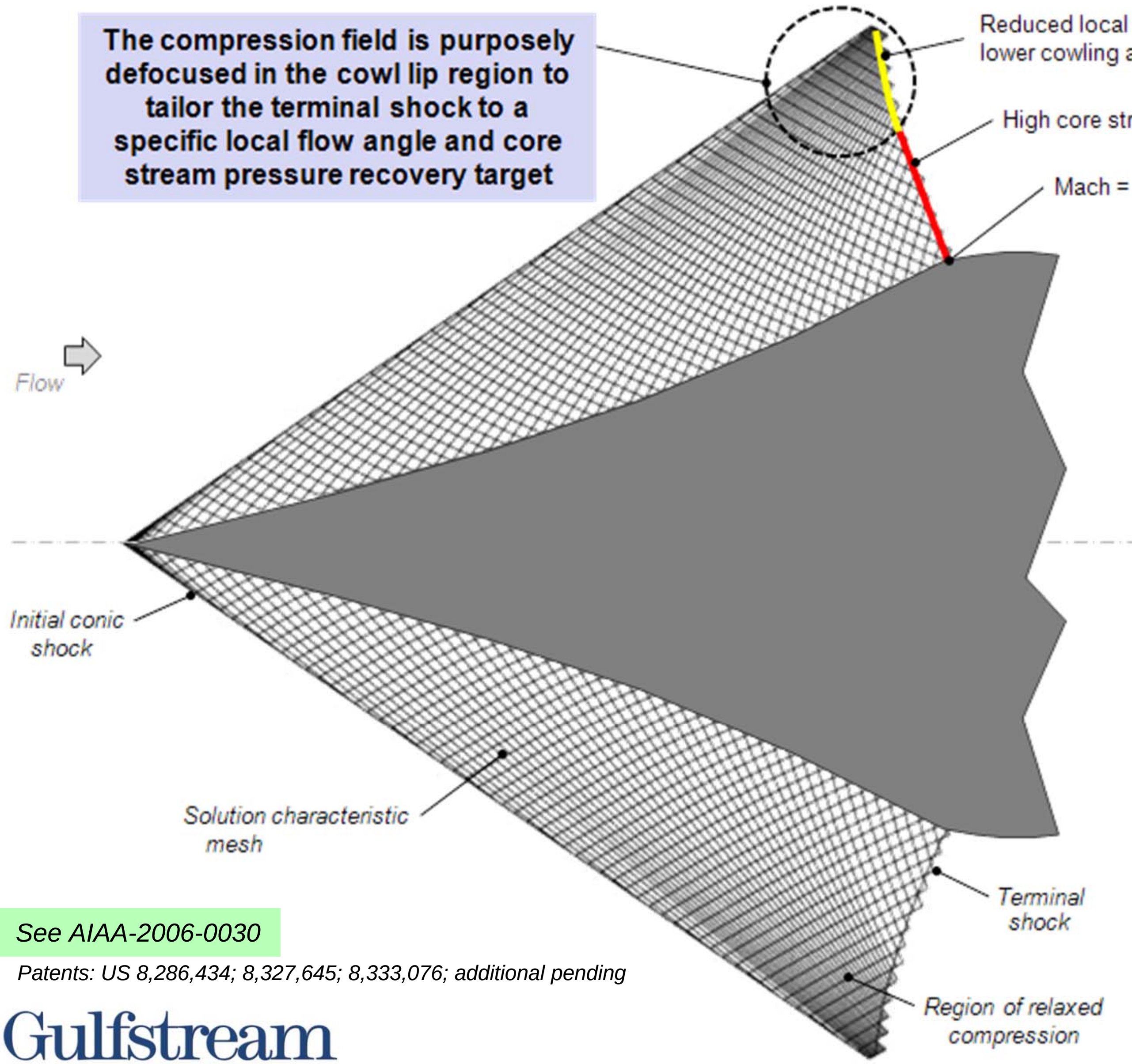
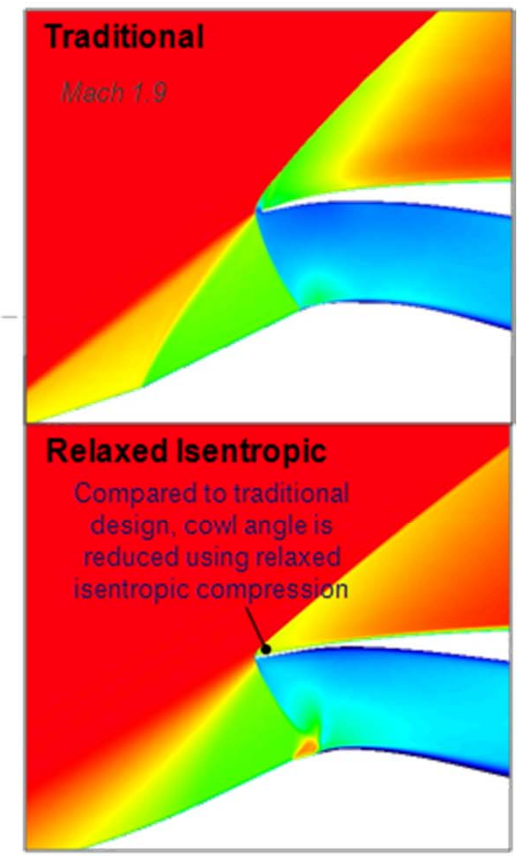
Reducing Cowling Angle with Relaxed Isentropic Compression





See AIAA-2006-0030

Patents: US 8,286,434; 8,327,645; 8,333,076; additional pending

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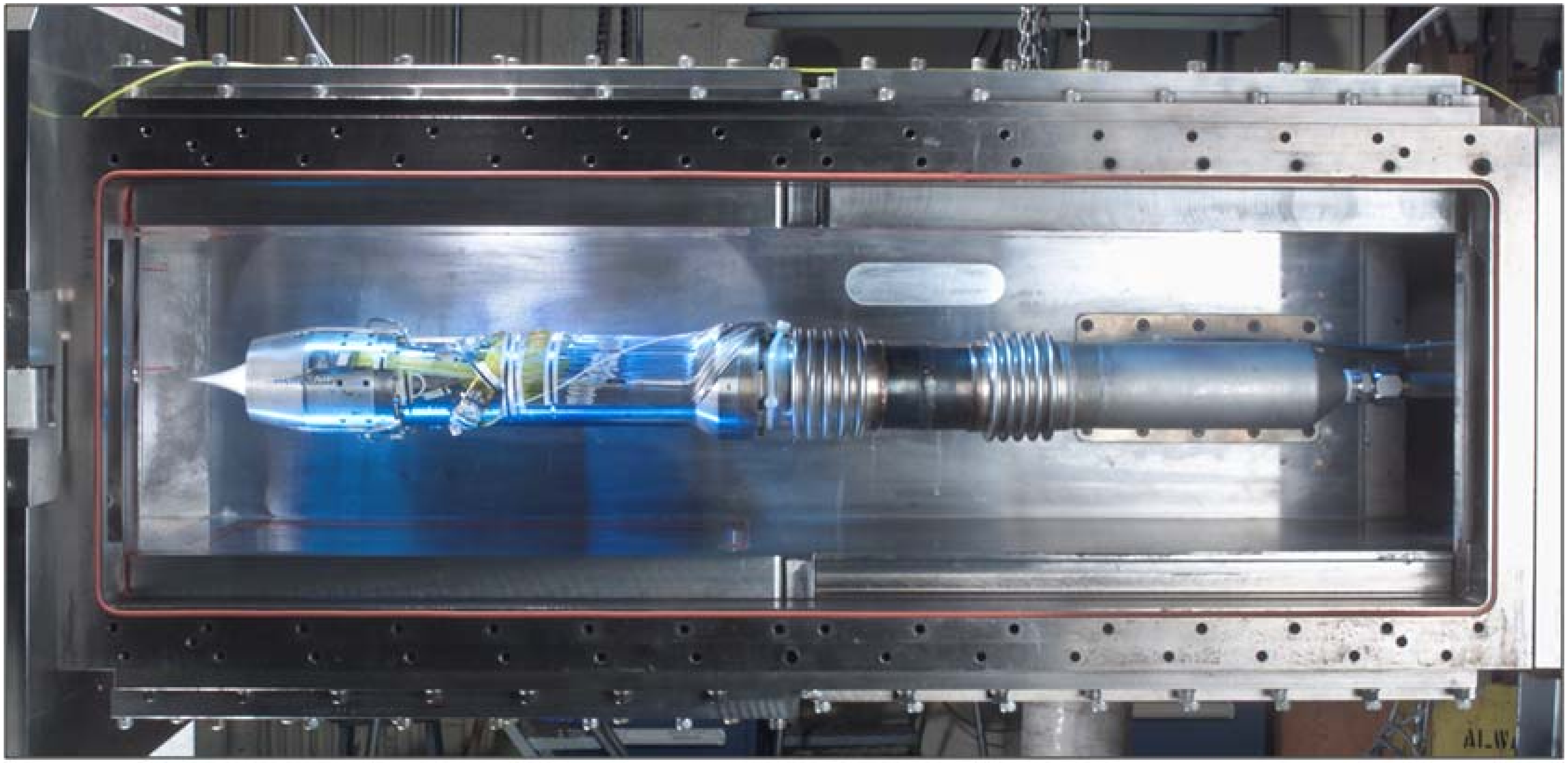
Relaxed Isentropic Compression Inlet Test Model at 1x1 SWT



Mach 1.97 design speed

Photo C-2006-840. Courtesy of NASA

See AIAA-2007-5066

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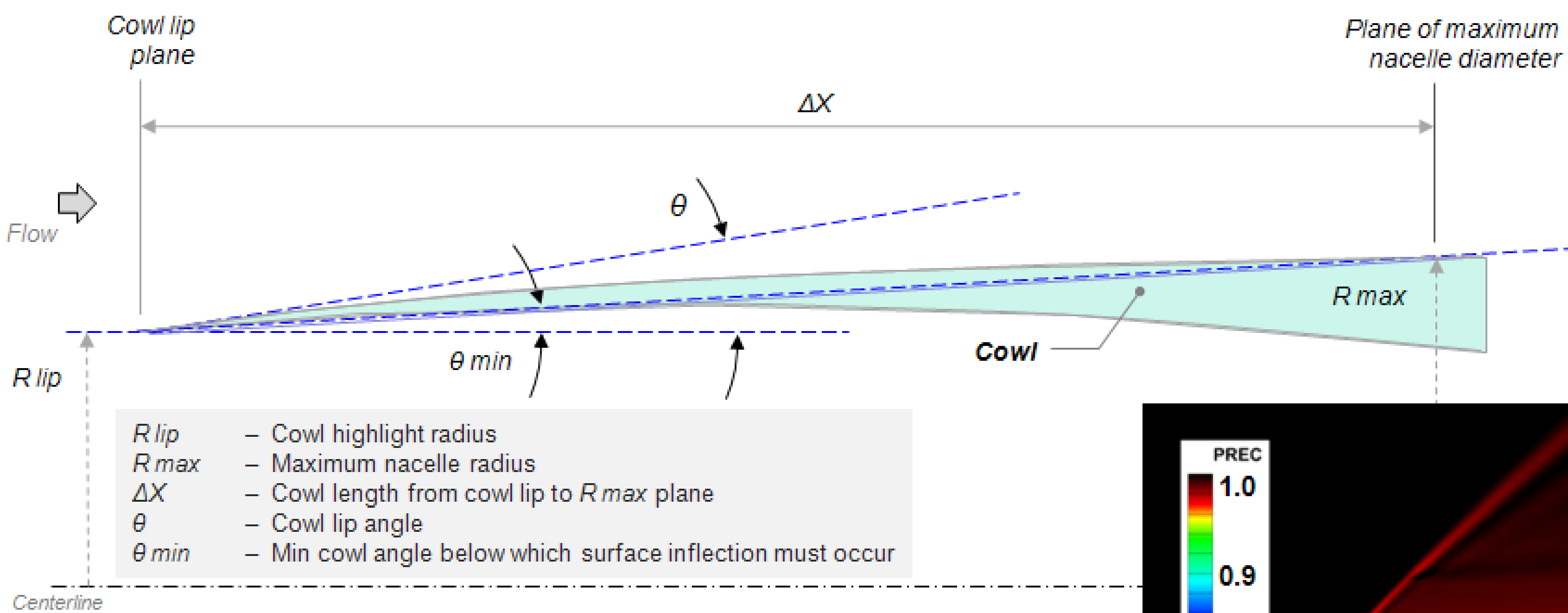
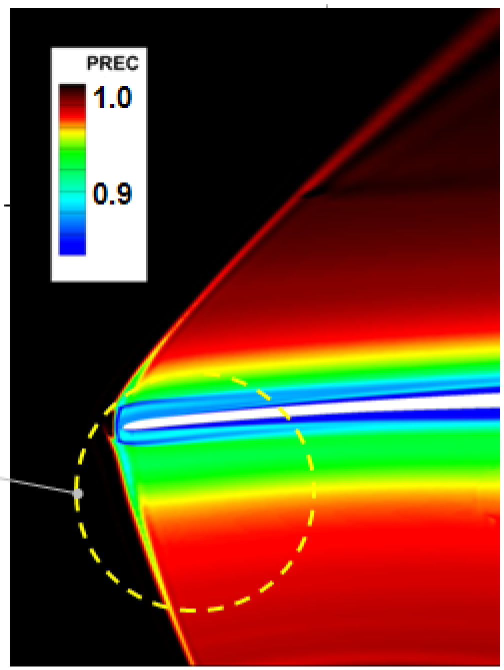
The Benefits of Relaxed Compression by Itself Can be Limited



$\theta\ min = atan\ ((R\ max - R\ lip) / \Delta X)$

If relaxed compression takes cowl angle below theta min, no real improvement in boom or drag occurs because of cowl surface inflection

Relaxed compression creates greater shock loss and higher post-shock distortion in cowl lip region



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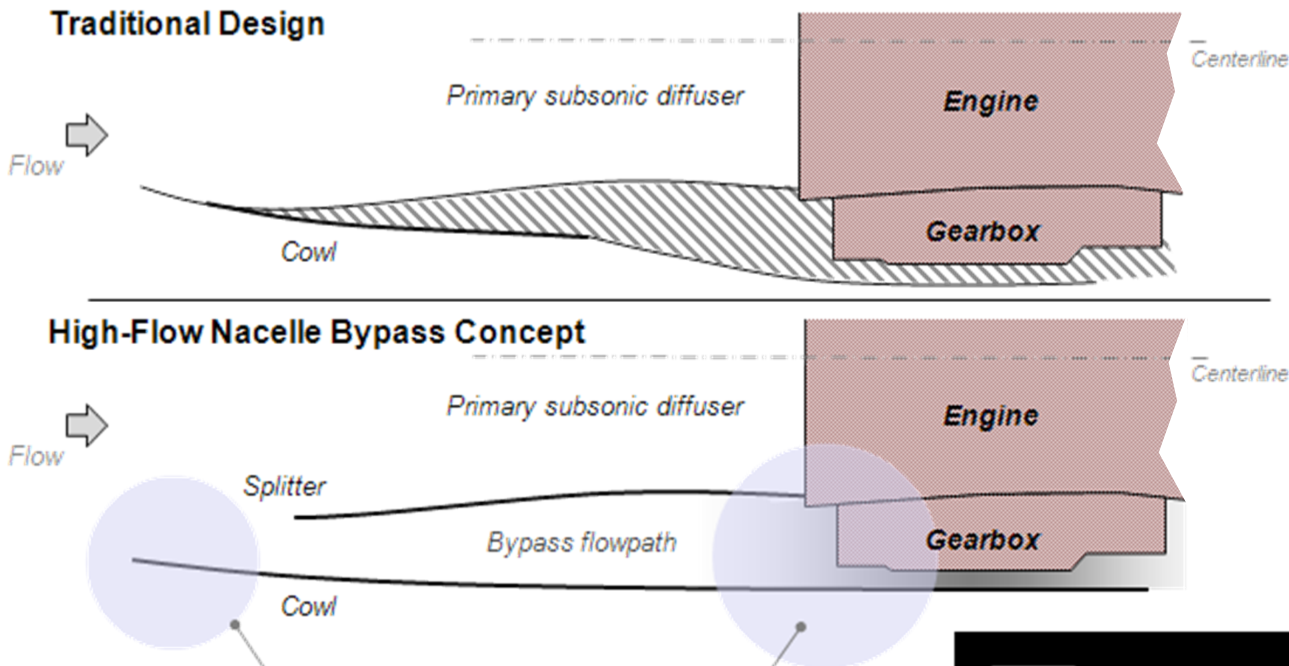
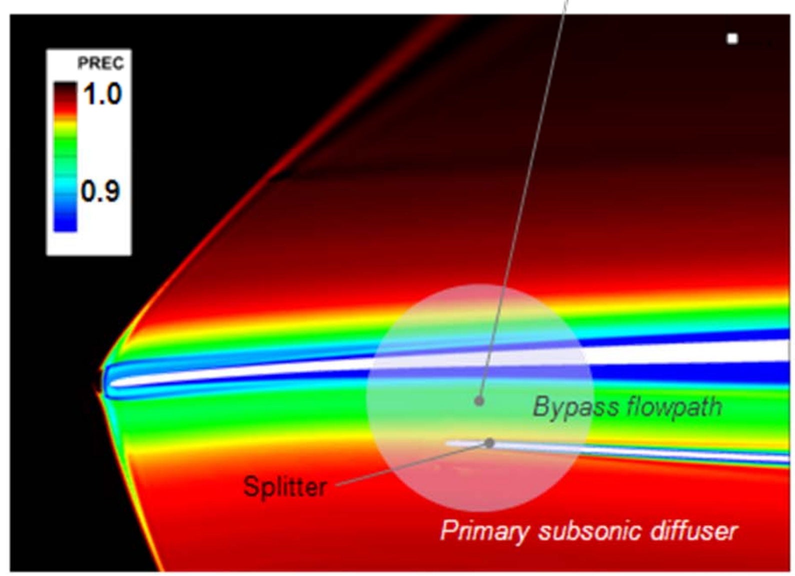
Nacelle Bypass Concept Extends Value of Relaxed Compression



A properly positioned splitter can fully capture the tip defect created by relaxed isentropic compression

The additional flow capture afforded by the bypass permits a more streamlined cowling, especially ahead of the gearbox protuberance

Internal channeling and fairings are required to maneuver the additional flow around the gearbox and other external hardware (see Figs. 8 and 9)



See AIAA-2011-3797

Patents: US 8,393,158 and 8,739,514; additional pending

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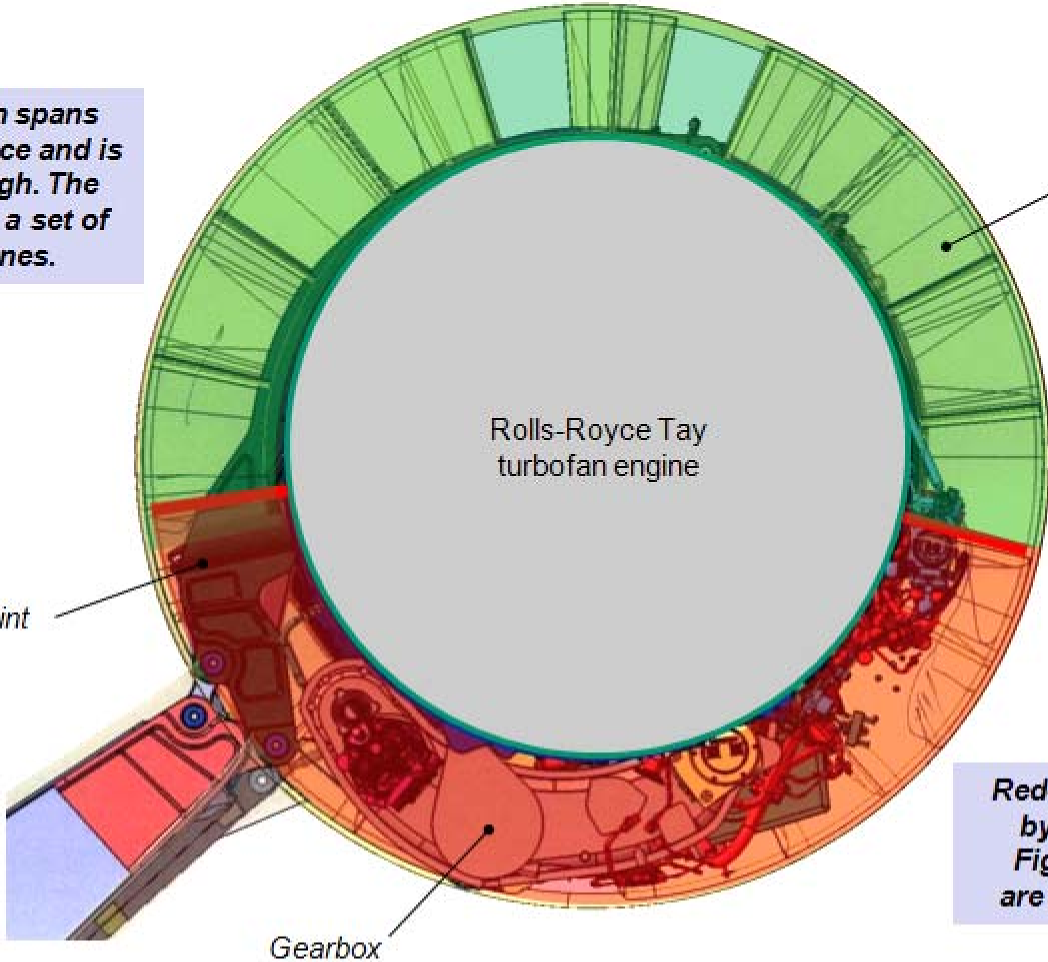
Unblocked Area for High-Flow Bypass Can be Surprisingly Large

Green-shaded region spans 200 deg circumference and is open to flow-through. The internal structure is a set of curved guide vanes.



Red-shaded region is isolated by fore and aft fairings (see Fig. 9). Engine mount points are also located in this region.

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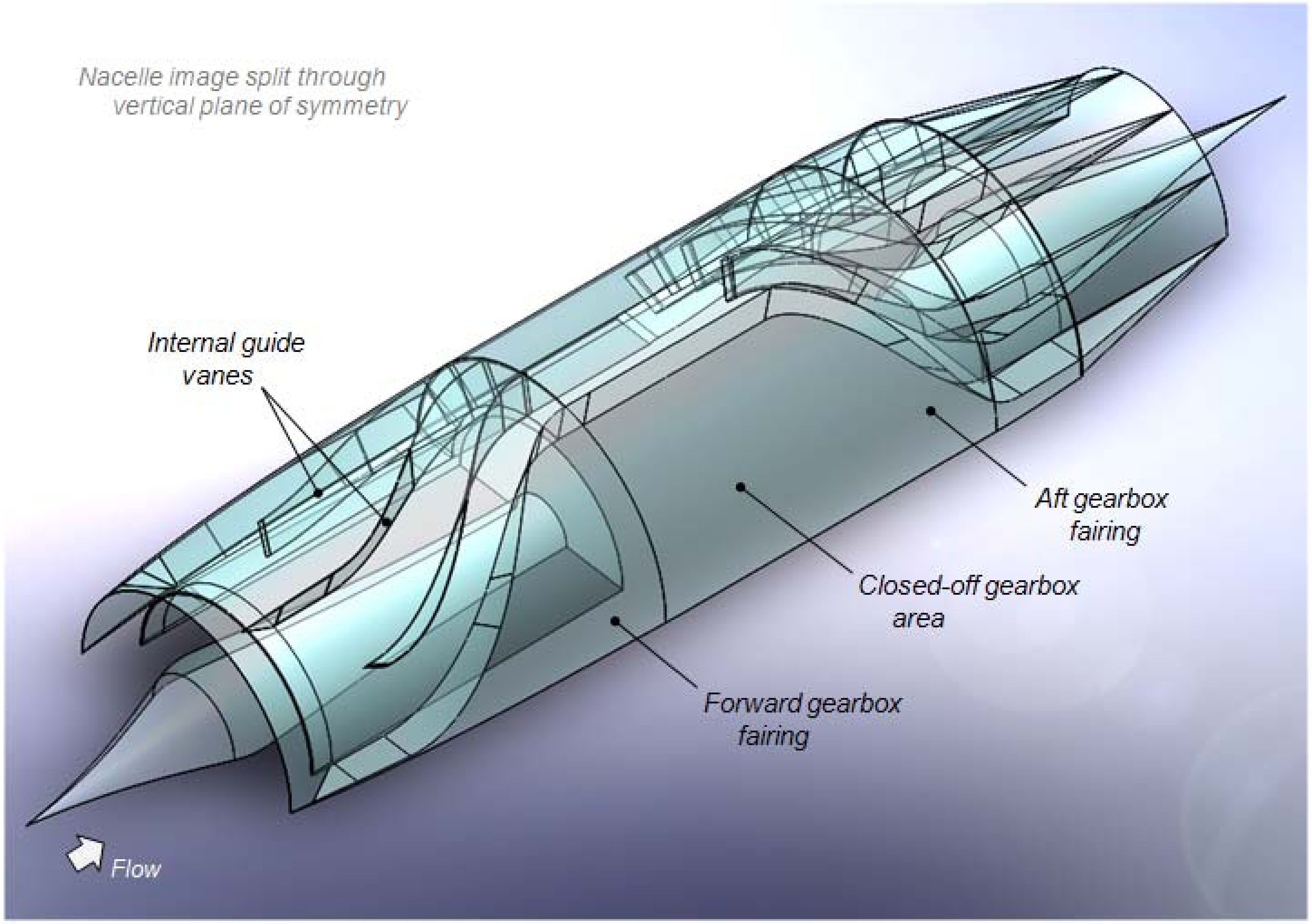
Tay-Based Example of High-Blow Bypass Channel Routing



See AIAA-2010-0480

Image courtesy of NASA

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Large-Scale Inlet/Bypass Test Model in NASA 8x6 SWT

Featuring both relaxed isentropic compression and high-flow nacelle bypass

See AIAA-2011-3796

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Full-Scale High-Flow Bypass Nacelle on G450 for Ground Test

See AIAA-2011-3797

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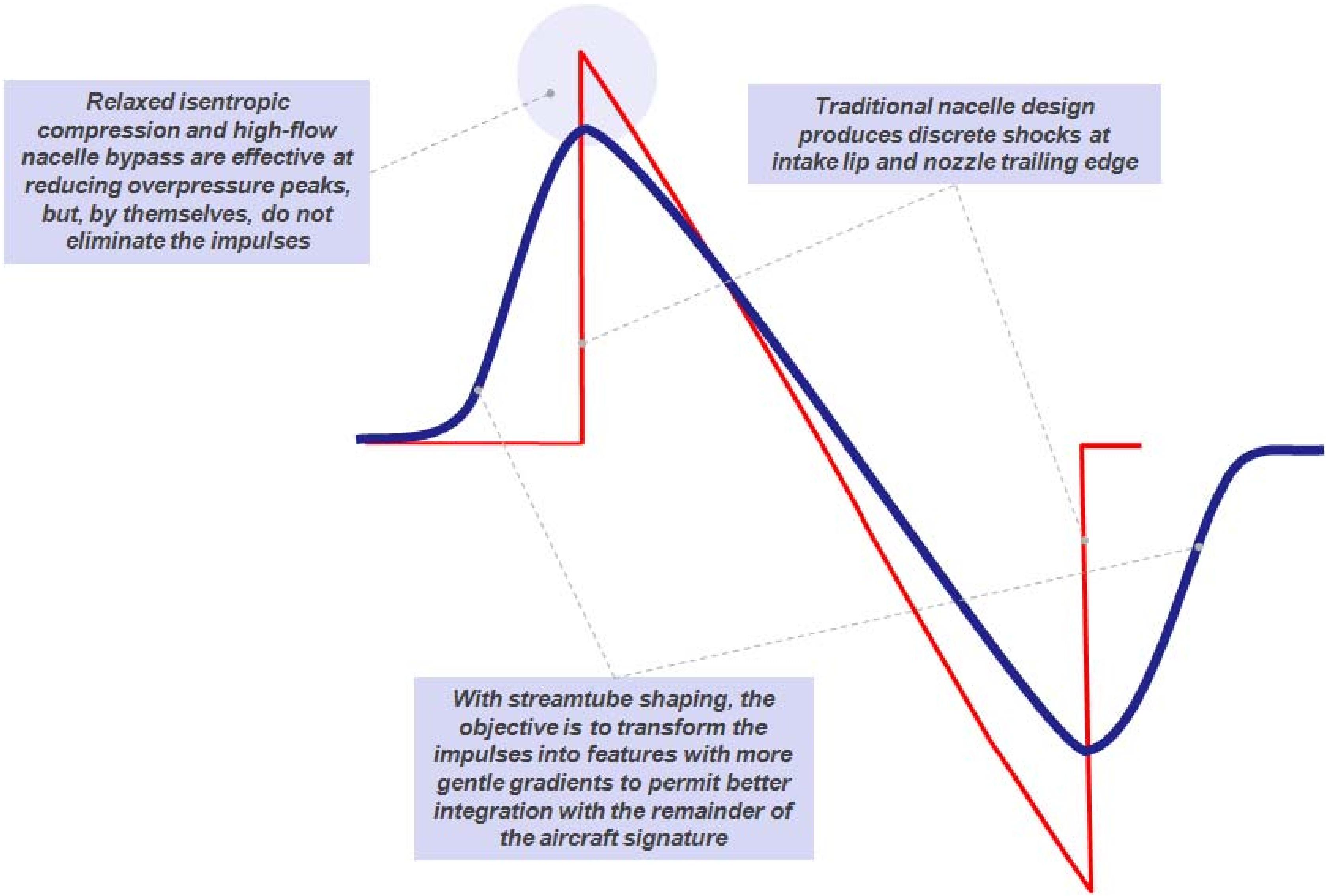
Low-Boom Objective: Diffuse the Nacelle-Generated Impulses



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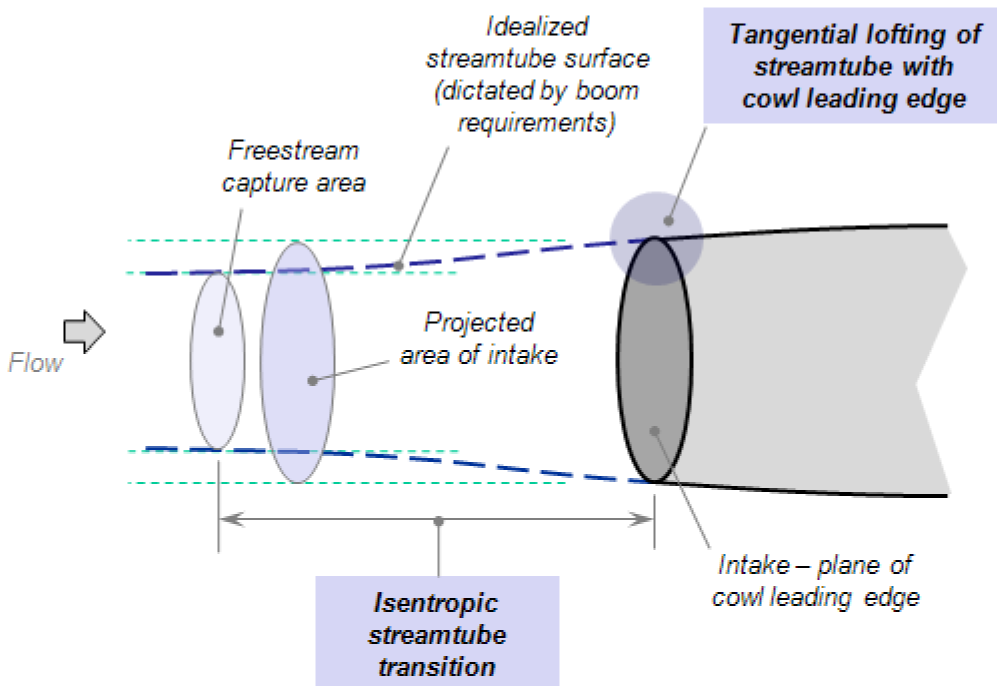
Necessary Mechanisms for Eliminating Nacelle's Shock Features



At the aft end of the nacelle, the necessary mechanisms are similar for the establishment of the streamtube geometry as it transitions off the nozzle trailing edge

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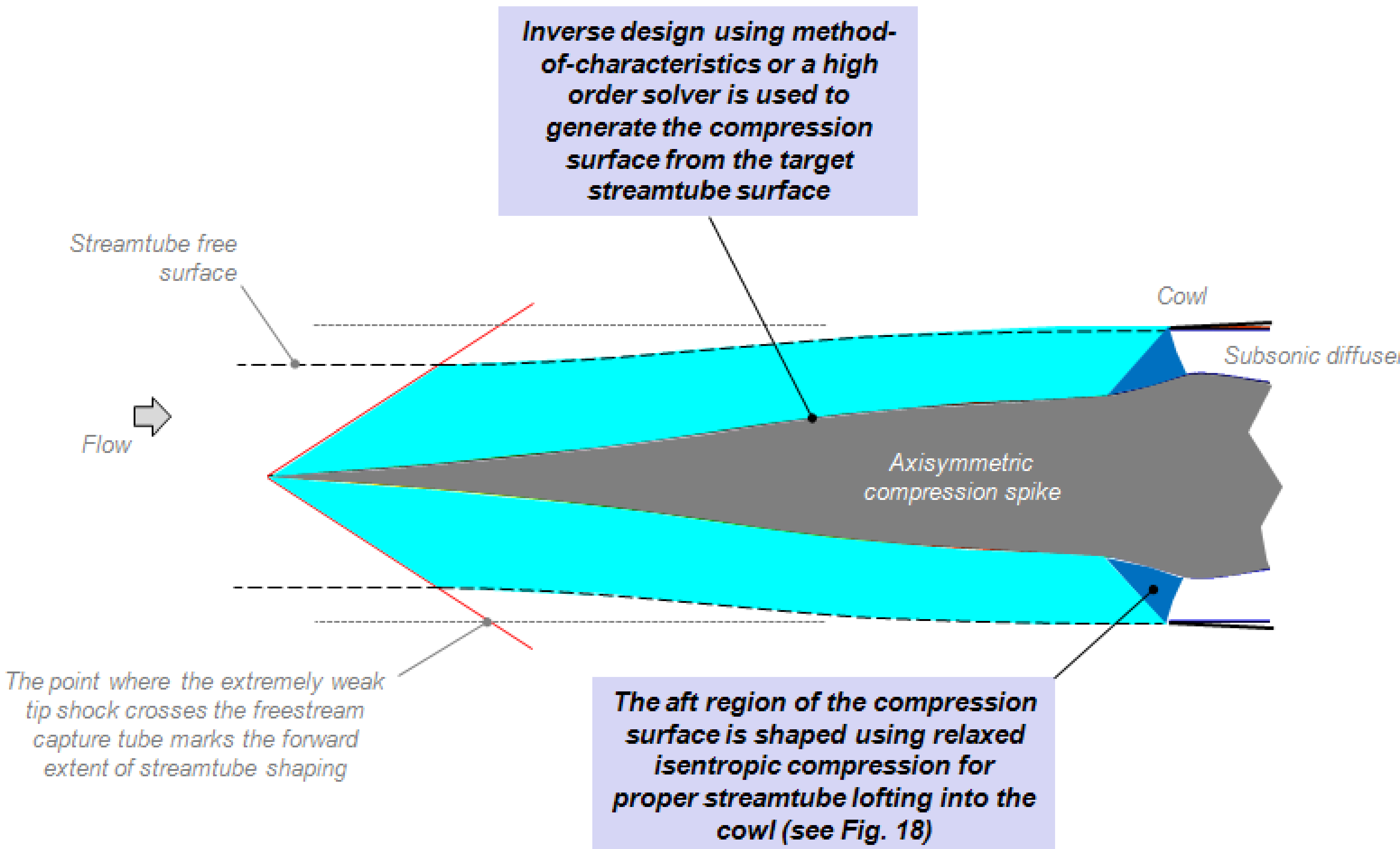
Inverse Design Using Streamtube Target: Compression Surface



Patent pending; see application US 2013/0042922

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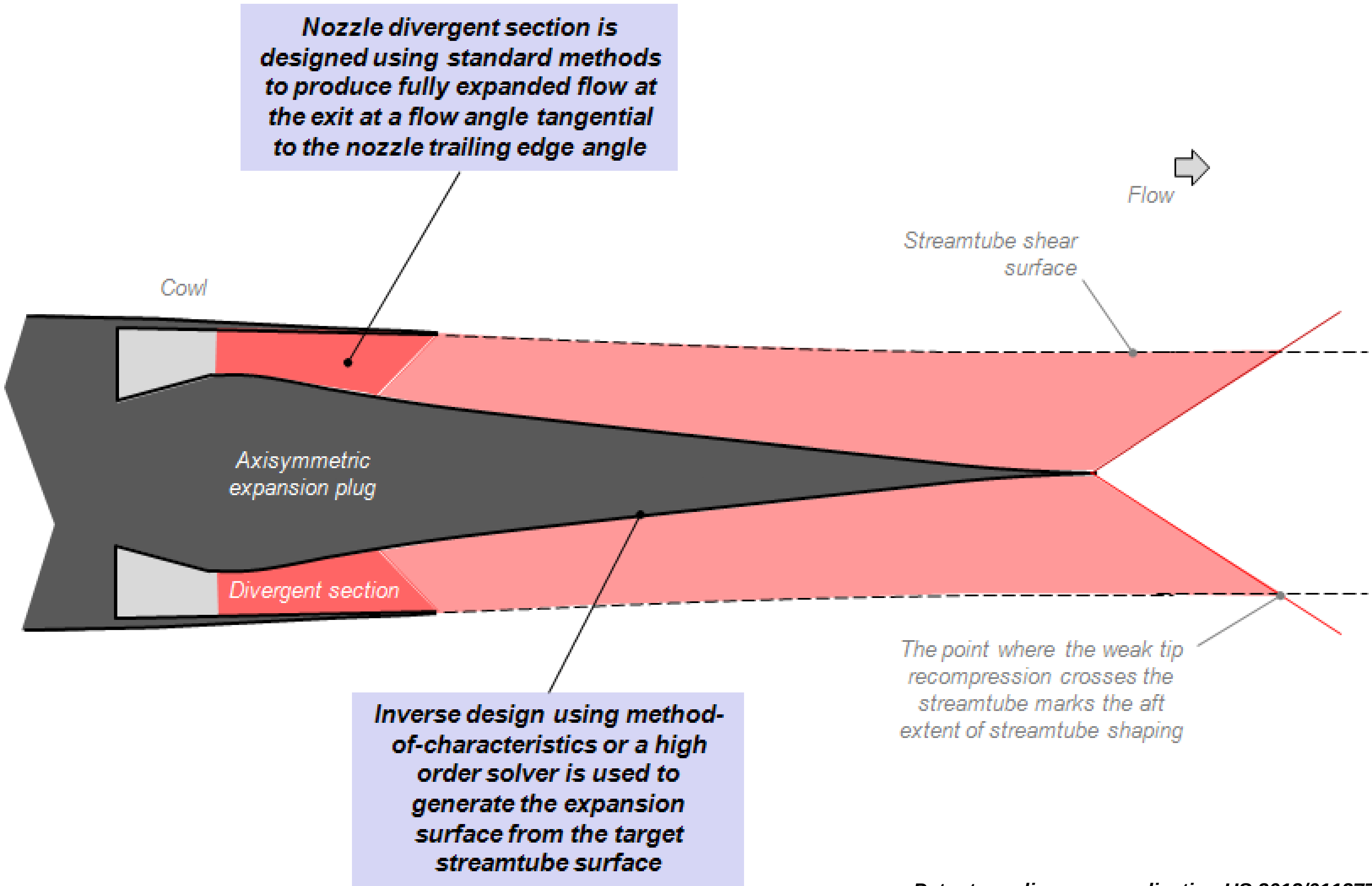
Inverse Design Using Streamtube Target: Expansion Surface



Patent pending; see application US 2013/0112776

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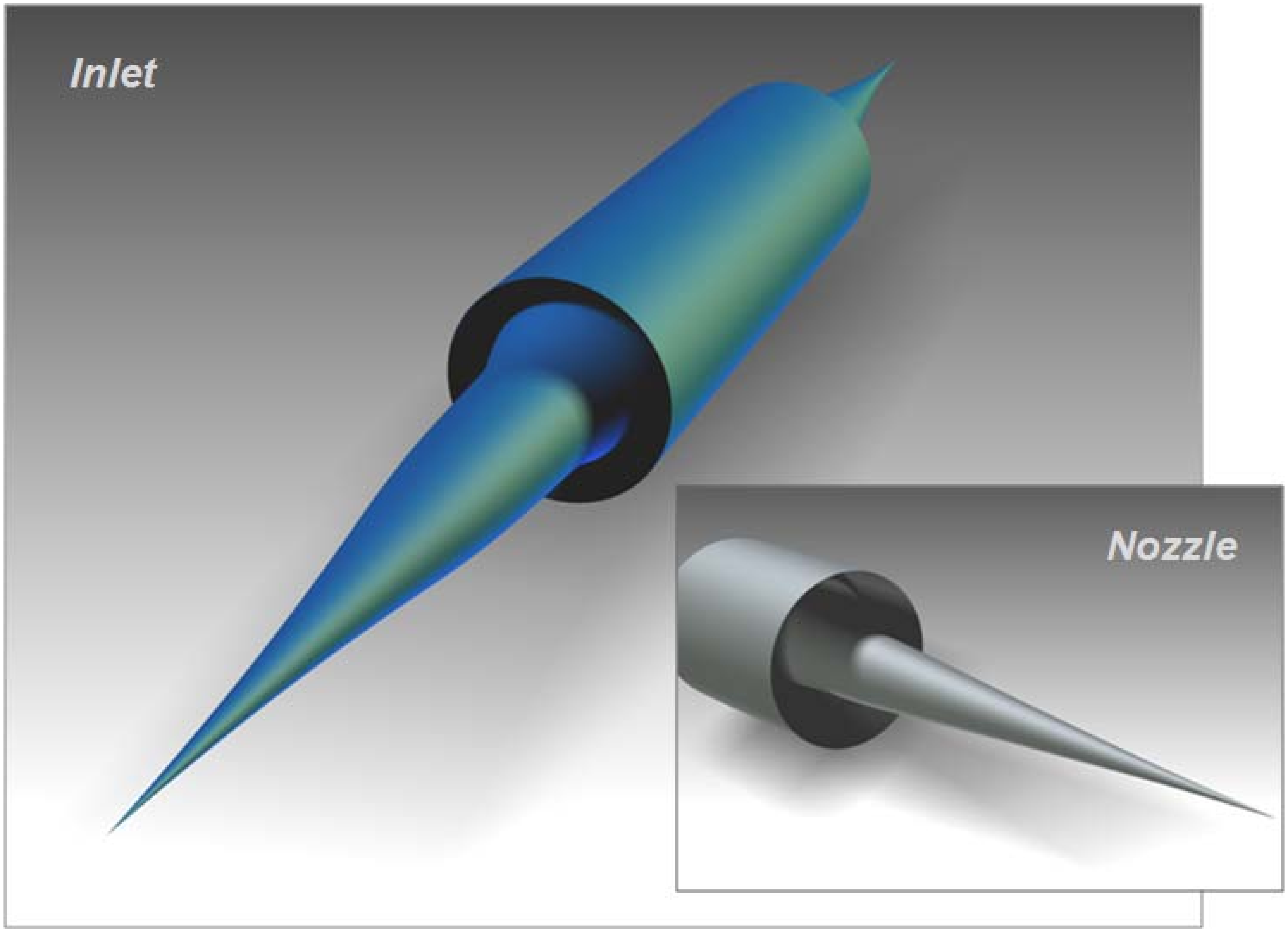
Streamtube Shaping Can Produce Long Extensions



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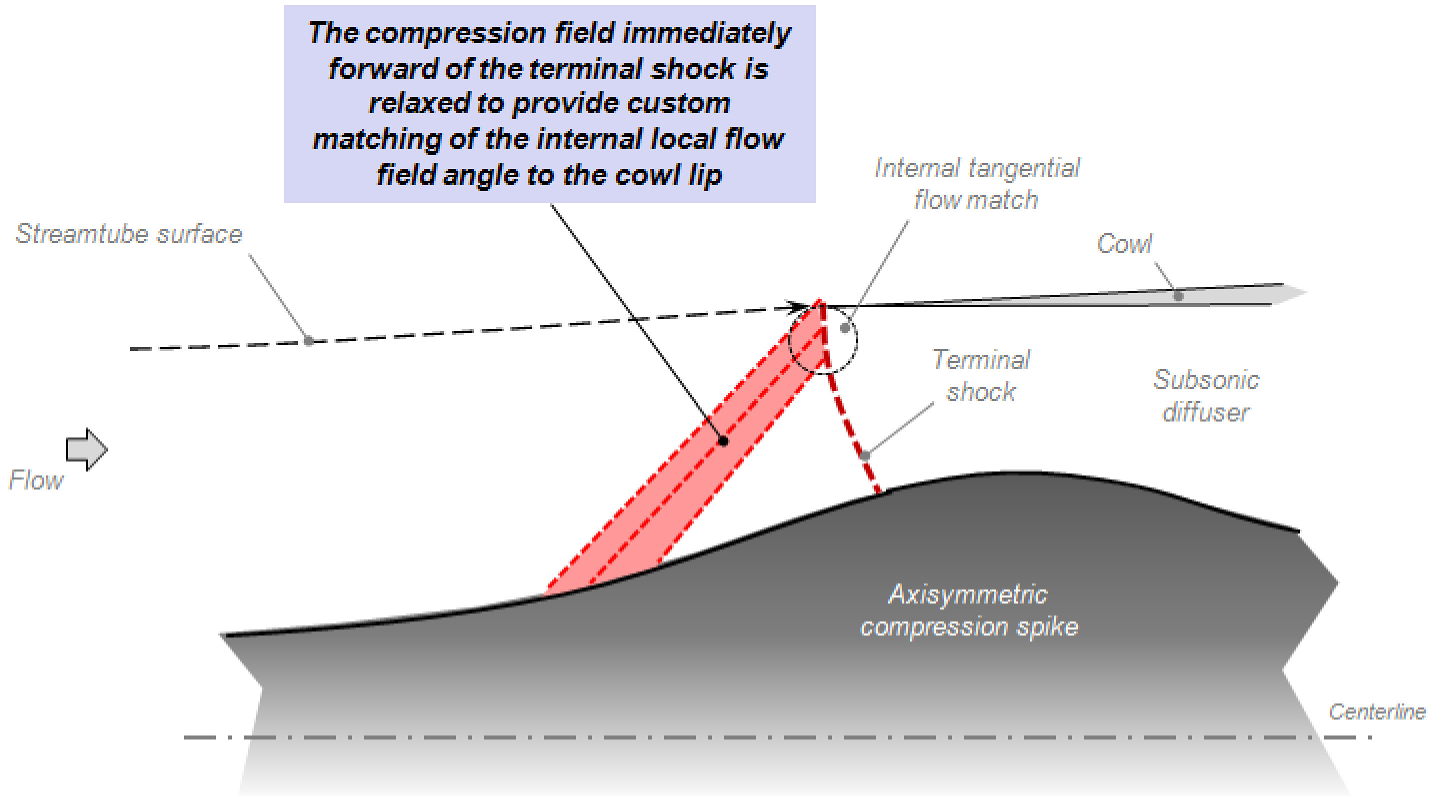
Relaxed Compression Matches Flow Angle at Cowl Lip



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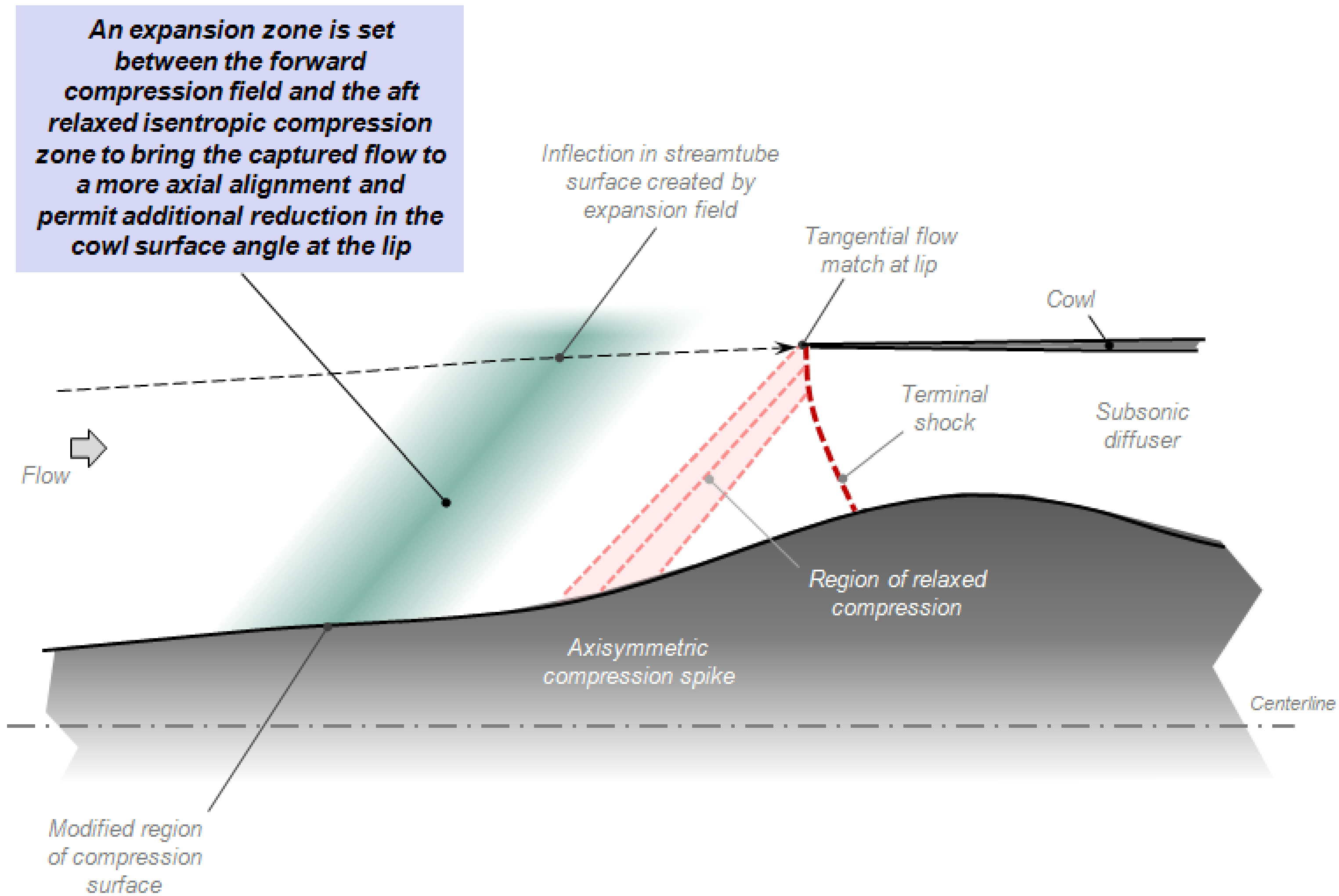
Interspaced Expansion Zone Enables True Nacelle Stove-Piping



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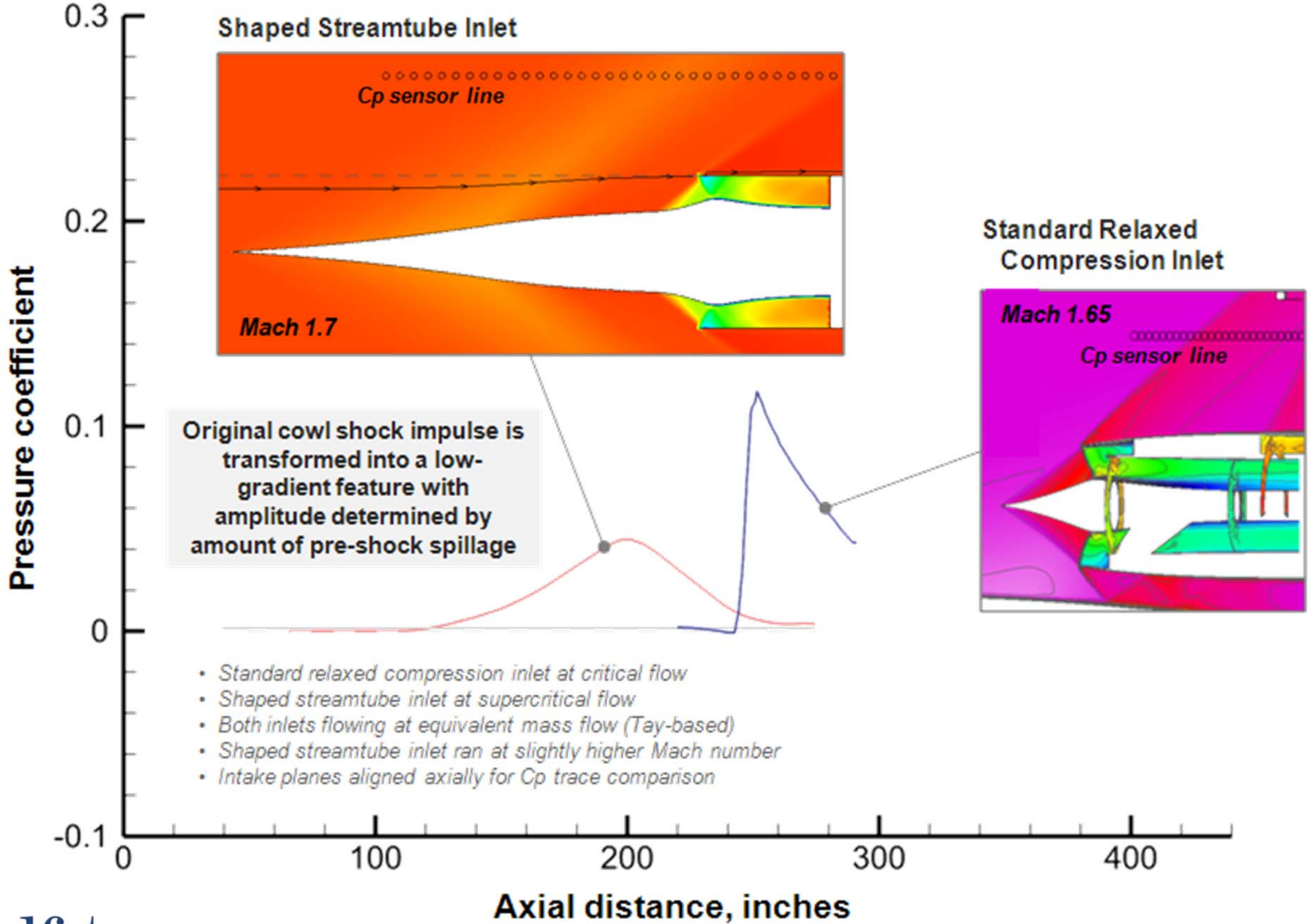
Transforming Forward Nacelle Shock Using Streamtube Shaping



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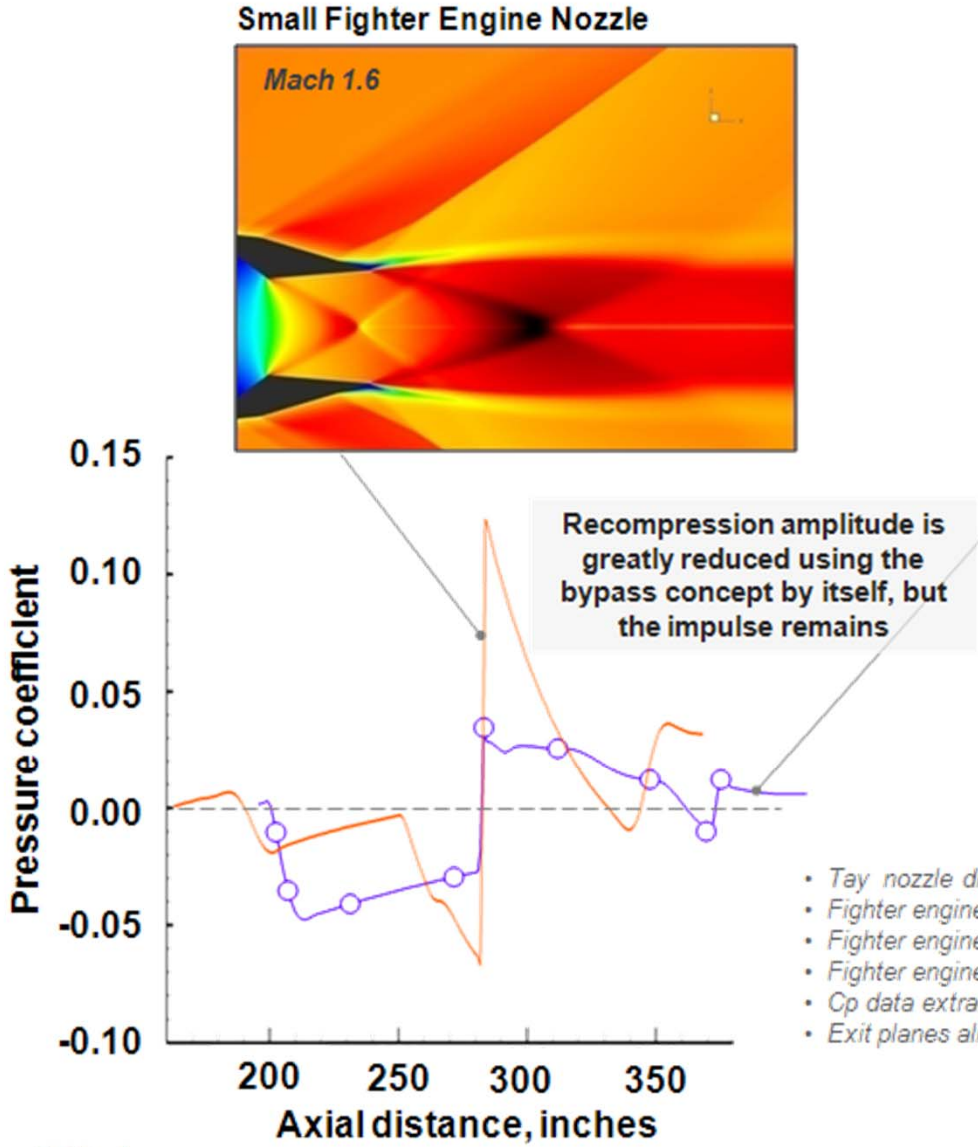
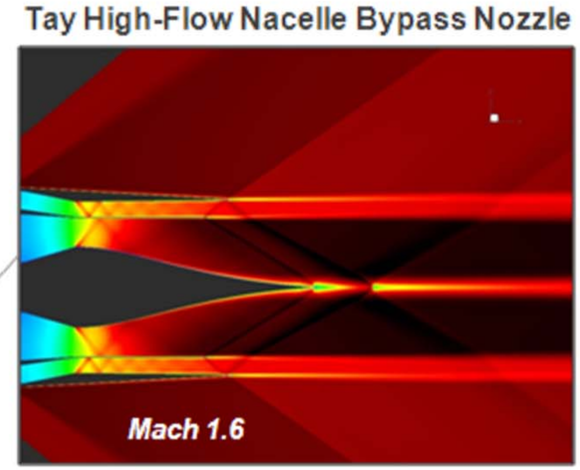
Transforming Aft Nacelle Shock with High-Flow Nacelle Bypass





- *Tay nozzle diameter is* ***2.5 times larger*** *than fighter engine's*
- *Fighter engine is at maximum non-augmented power; Tay at max power*
- *Fighter engine is of similar thrust-class to Tay at supersonic design point*
- *Fighter engine has much lower exhaust mass flow at equivalent thrust*
- *Cp data extracted along axial cut at equivalent distance from centerline*
- *Exit planes aligned axially for Cp trace comparison*

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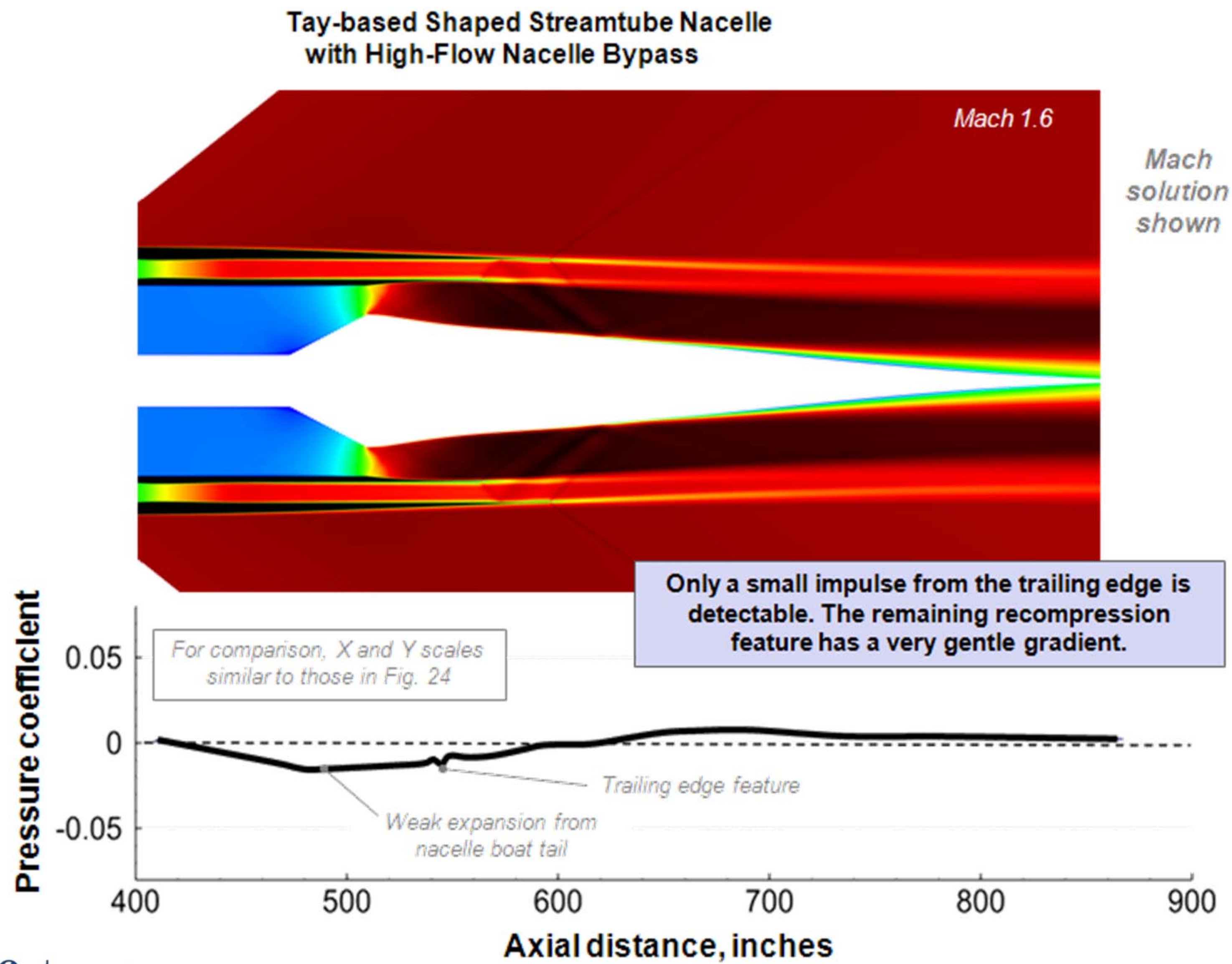
Eliminating the Aft Nacelle Shock Using Streamtube Shaping



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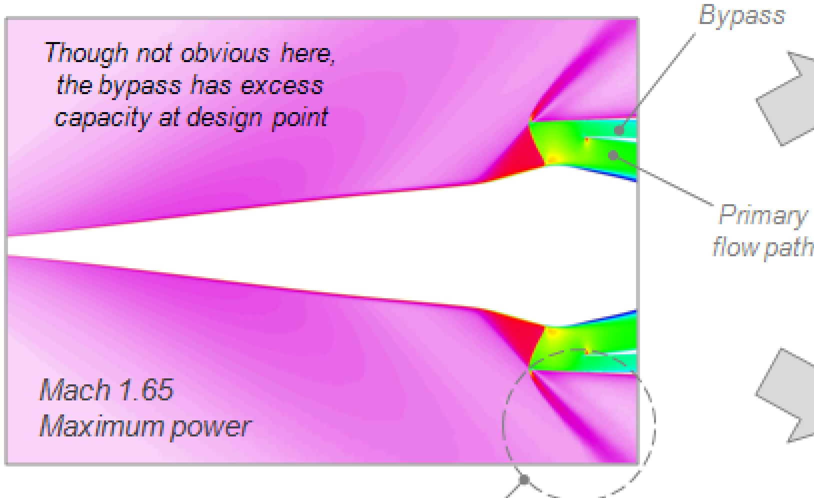
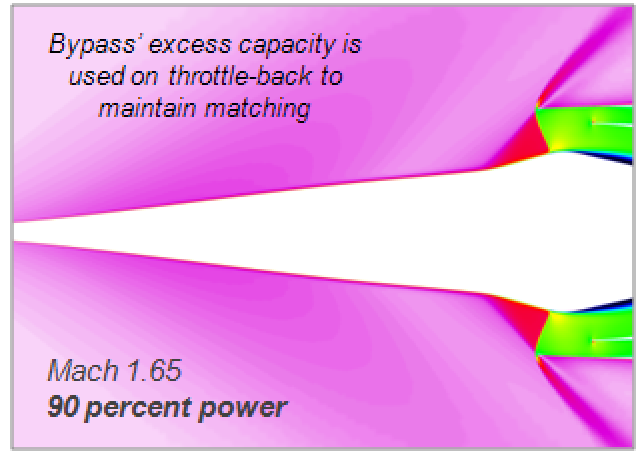
High-Flow Nacelle Bypass is Useful for Off-Design Matching

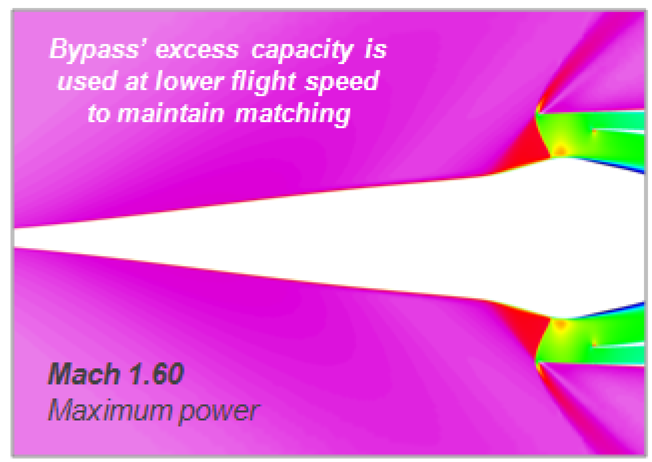
Shaped streamtube inlet system sized for Tay engine operating at Mach 1.65 over-wing condition at maximum power. High-flow nacelle bypass and relaxed isentropic compression included.



Note: The color scale on these Mach contours was selected to emphasize flow features. The escaping compression due to spillage is actually very weak.



Mach solutions shown



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Conclusion

- Relaxed isentropic compression and high-flow nacelle bypass are effective, but not necessarily sufficient, for ultra-low boom design
- The streamtube shaping concept was developed to eliminate all remaining strong discrete impulses in the local pressure field
- Integrated low-boom design is simplified and pressure drag is reduced
- Several challenges are introduced but are manageable:
  - Boundary layer growth and distortion
  - Recovery loss
  - Nozzle flow dynamics
- Combined with relaxed isentropic compression and high-flow bypass, the method expands the design space and provides off-design robustness
- Streamtube shaping is potent, predictable, and adaptable

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Backup Slides

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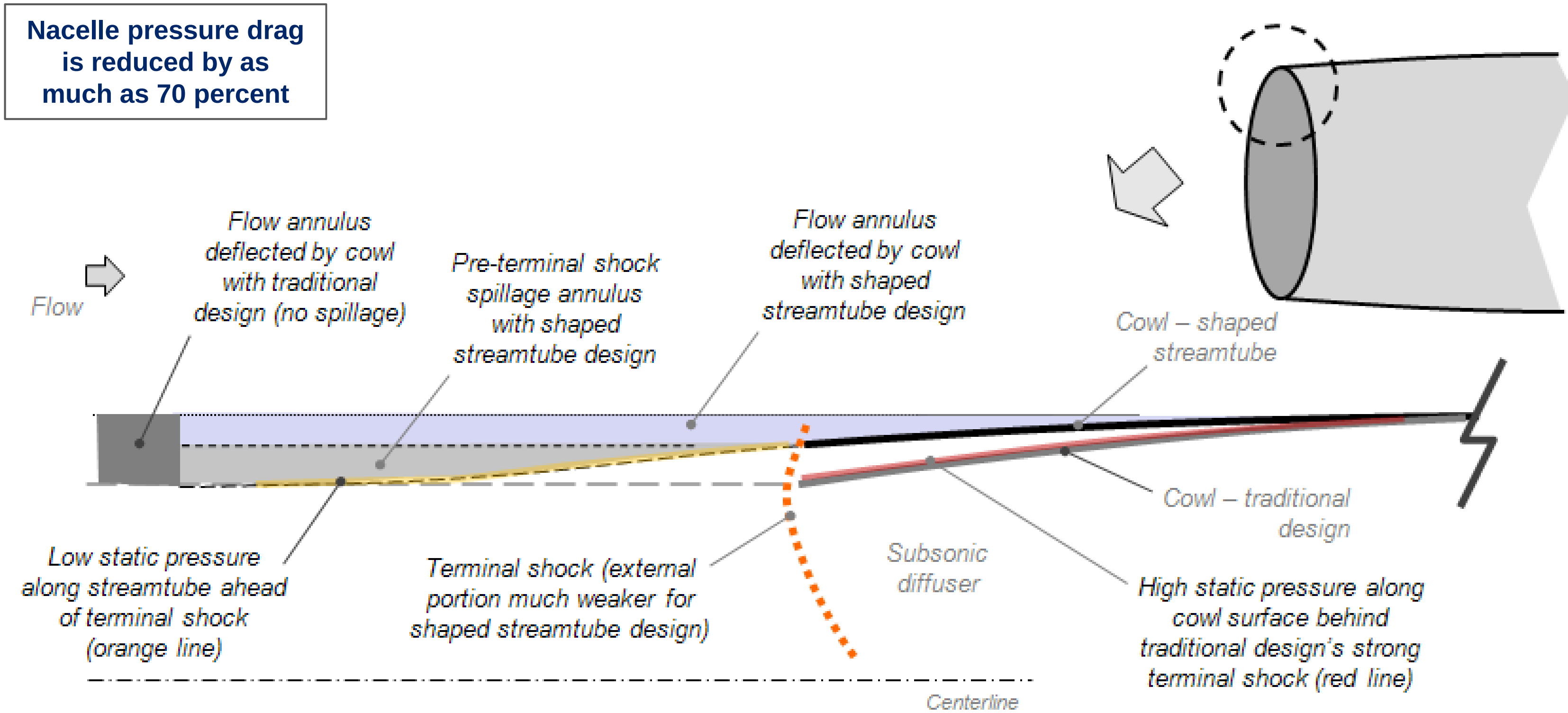
Disturbance *and Drag* Reduction Using Streamtube Shaping

Nacelle pressure drag is reduced by as much as 70 percent



Considering the associated pressure fields, the drag due to pre-terminal shock spillage using shaped streamtube is much less than the drag due to cowl profile deflection for a traditional design

The mechanisms are similar for the reduction of boat tail drag ahead of the nozzle trailing edge

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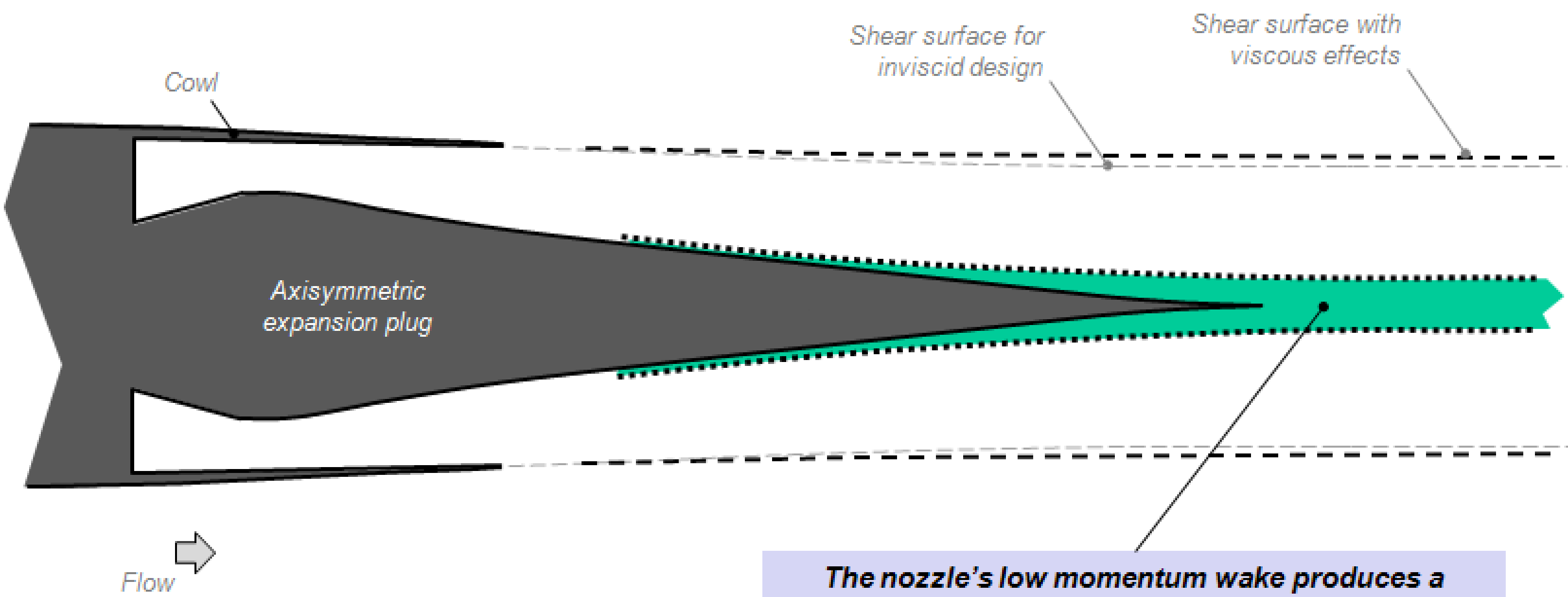
Viscous Mechanisms in Exhaust Can be Put to Use Effectively



The nozzle's low momentum wake produces a larger jet plume volume for equivalent exhaust mass flow. This permits designing to a larger streamtube possessing a more gentle surface gradient and less impact to the local pressure field.

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