Parametric study of the performance of two-dimensional scramjet intake

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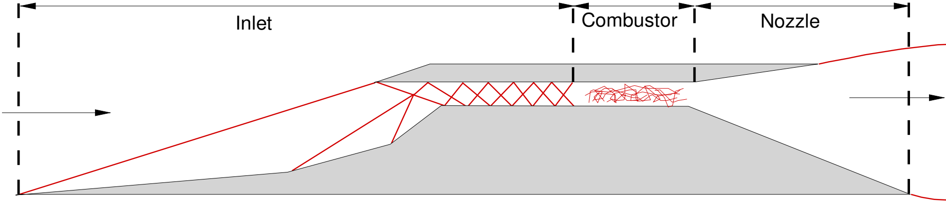
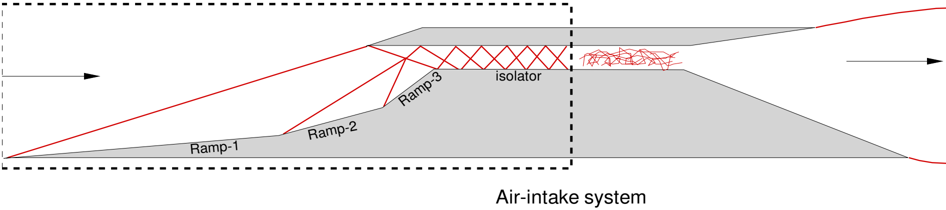
Outline

Schematic of scramjet engine



Schematic of scramjet engine

Primary objectives in designing efficient inlet



1. Near to isentropic and high pressure recovery.
2. High capture area (high mass flow).
3. Uniform flow.
4. Wide range of operation.

Performance parameters

Static temperature ratio

$$\psi = \frac{T_{exit}}{T_{inlet}}$$

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Kinetic energy efficiency

$$\eta_{KE} = 1 - 0.2\left(1 - \frac{M_{exit}}{M_{inlet}}\right)^5$$

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Captured mass flow rate

$$\dot{m}_c = \rho A_c V_{inlet}$$

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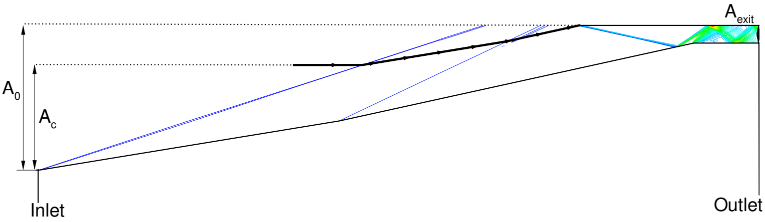


Outline

Objective

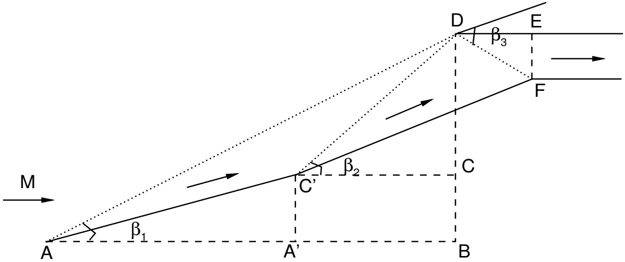
1. Design a scramjet inlet (at a cruising flight Mach number-6.5).
2. Effect of angle of attack, α.
3. Effect of cowl deflection angle, θ_c.

Outline

Inlet Design

Design criteria:

1. Shock-on-lip condition
2. Uniform flow

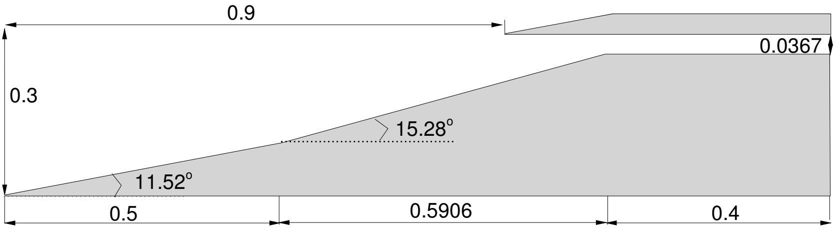


Input parameters

1. Mach number (M)
2. First ramp length (AA').
3. Distance of the cowl tip from the first ramp leading edge (AB).
4. Total intake height (DB).

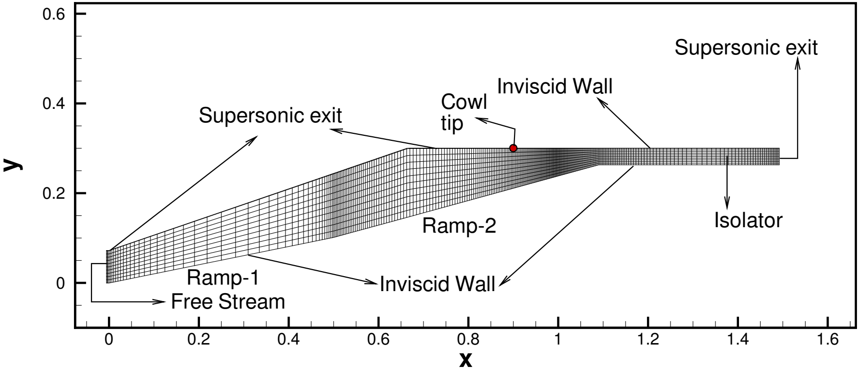
Physical and Computational domain

Details of scramjet intake geometry (All dimensions are in meters)



Physical and Computational domain

Grid structure and boundary conditions.



550 x 250 grid points, with x-stretching factor of 1.28

Numerical methodology

1. In-house code
2. Finite volume formulation
3. Modified Steger-Warming flux splitting *(Computers and Fluids, 1989)*
4. Implicit Data Parallel Line Relaxation method *(AIAA, 1998)*

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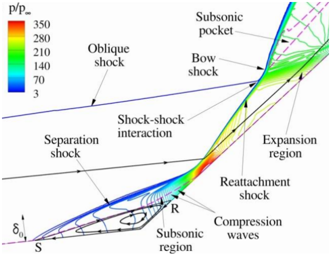
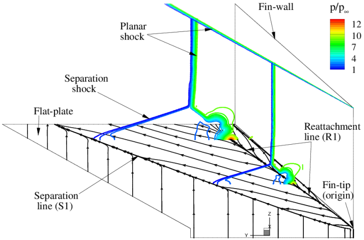


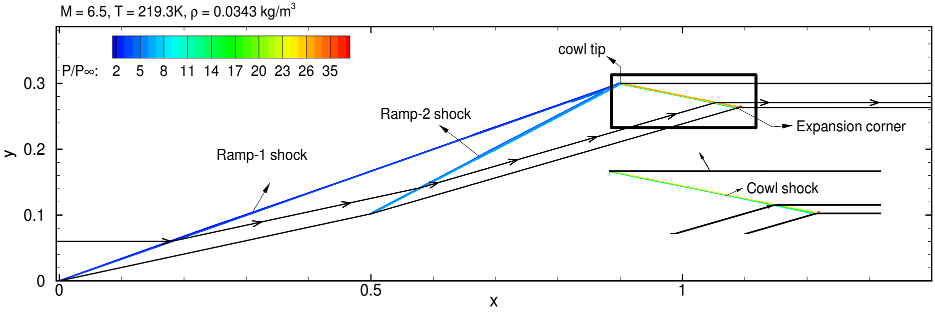
J. Propul. Power (2012)



AeSI CFD Sym. (2009)

Outline

On-design condition (M = 6.5)



Pressure contour of inlet for on-design Mach number at $\alpha = 0^\circ$ and $\theta_c = 0^\circ$.

Outline

Mach effect

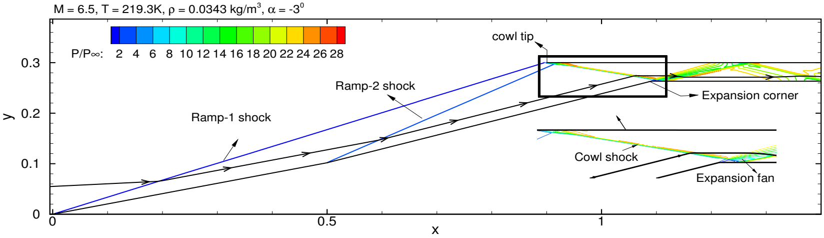
Table : Comparison of the analytical and numerical simulation results with respect to various parameters for scramjet inlet.

Mach	T_{iso}/T_{inlet}		$P_{o,iso}/P_{o,inlet}$		P_{iso}/P_{inlet}		M_{iso}	
	Theo.	CFD	Theo.	CFD	Theo.	CFD	Theo.	CFD
4.5	2.298	2.295	0.742	0.745	13.660	13.652	2.446	2.450
5.5	2.716	2.707	0.630	0.637	20.804	20.797	2.824	2.830
6.5	3.197	3.197	0.521	0.523	30.422	30.533	3.127	3.120
7.5	3.743	3.76	0.422	0.414	42.827	42.769	3.370	3.370

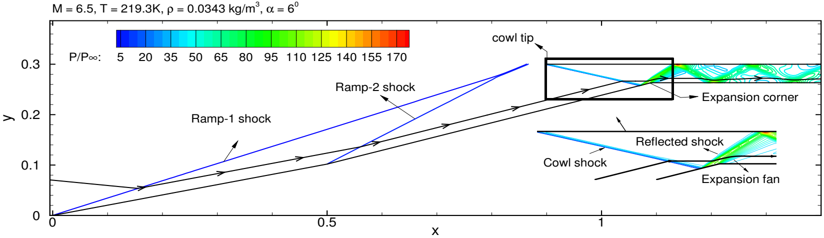
The difference is within the ± 2 % error range for all parameters.

Outline

Flow structure for varying α at M = 6.5

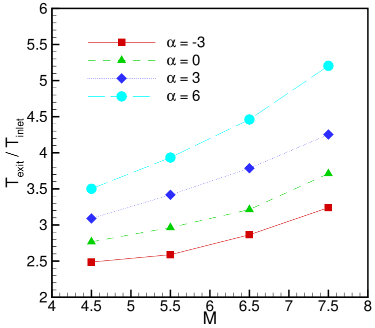


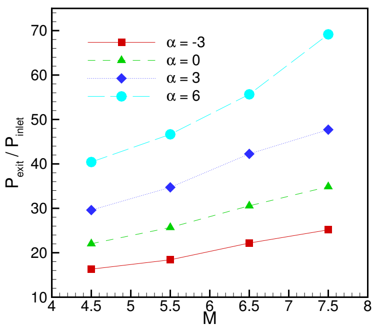
(a) $\alpha = -3^\circ$



(b) $\alpha = 6^\circ$

Performance parameters (varying α and M)





$\therefore$

At the fixed angle of attack, the strength of the shocks increases with increasing Mach number

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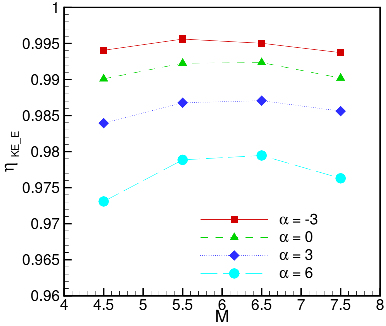
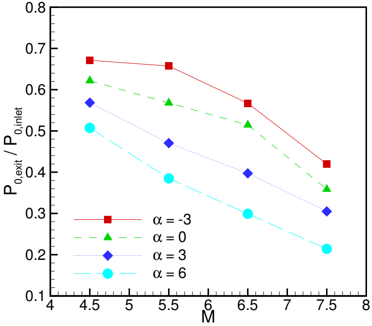
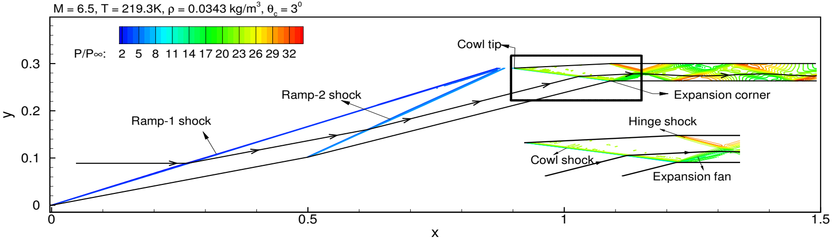




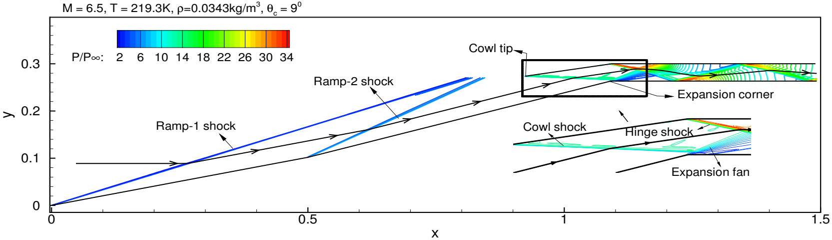
Maximum η_{KE} is observed at designed Mach number

Outline

Flow structure for varying θ_c at M = 6.5

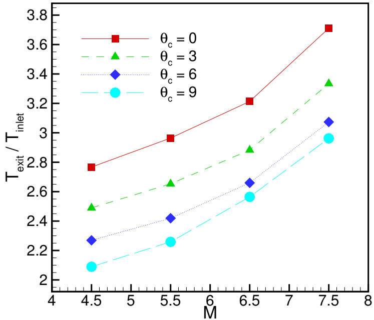


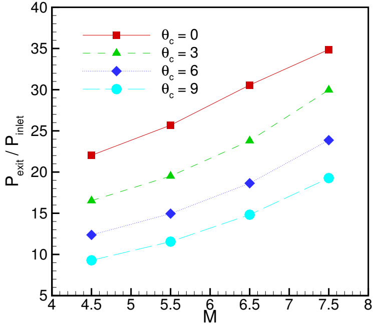
(a) $\theta_c = 3^\circ$



(b) $\theta_c = 9^\circ$

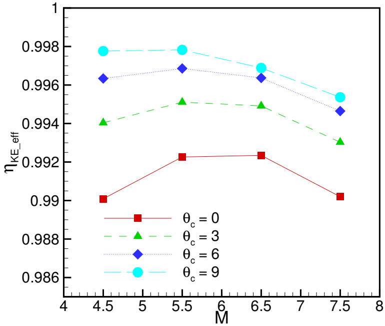
Performance parameters (varying Mach number and θ_c)

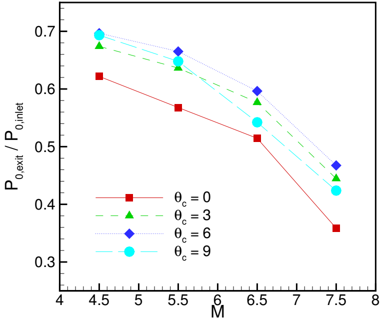




Compression ratios increases with M
Decreases with increasing θ_c

Continue...

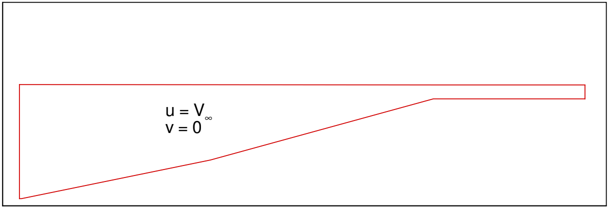




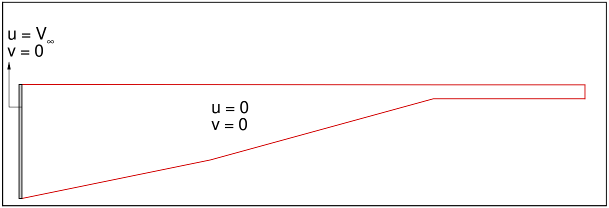
$\uparrow \theta_c$– shifts the maximum η_{KE} to lower Mach numbers

Outline

Flow initialization

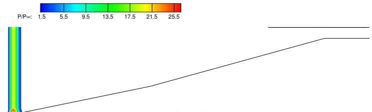


Earlier simulations: Free-stream velocity initialization

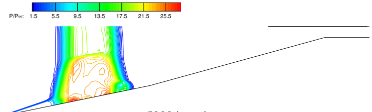


New Simulations: Zero velocity initialization

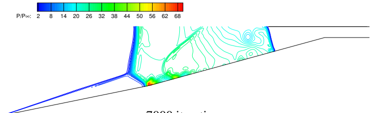
Unstarted mode



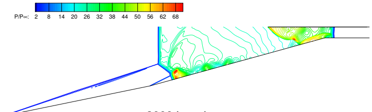
3000 iterations



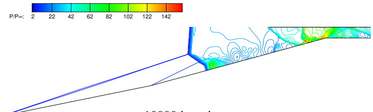
5000 iterations



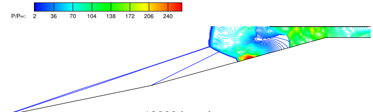
7000 iterations



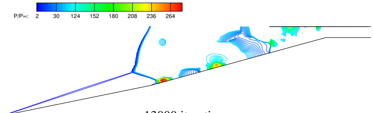
8000 iterations



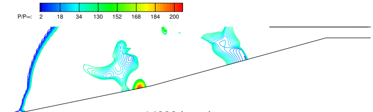
10000 iterations



12000 iterations

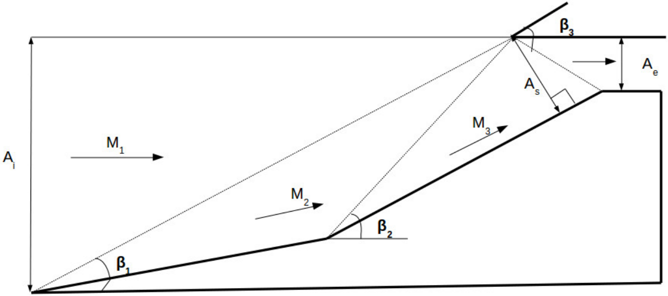


13000 iterations



14000 iterations

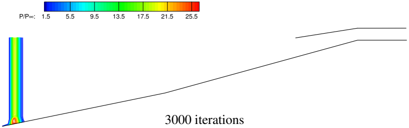
Starting criteria



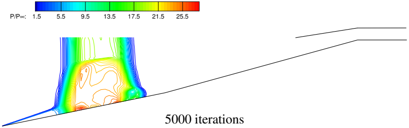
$$(A_e/A_s) \geqslant \left[\frac{\gamma-1}{\gamma+1} + \frac{2}{(\gamma+1)M_3^2}\right]^{\frac{1}{2}} \left[\frac{2\gamma}{\gamma+1} - \frac{\gamma-1}{(\gamma+1)M_3^2}\right]^{\frac{1}{\gamma-1}}$$

A_e is fixed and reducing the A_s by deflecting the cowl to meet Kantrowitz criteria
Self starting is achieved , $\theta_c = 9^\circ$

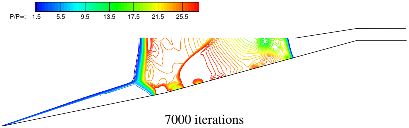
Started mode



3000 iterations



5000 iterations



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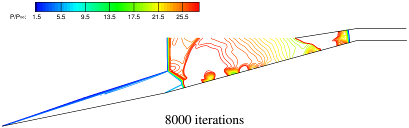
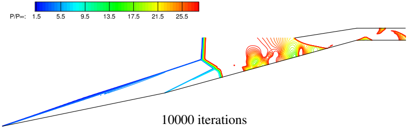
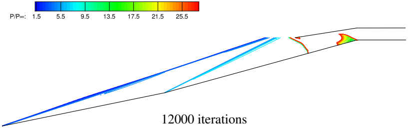


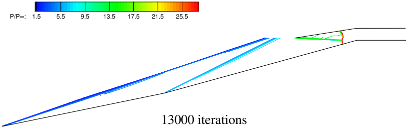
8000 iterations



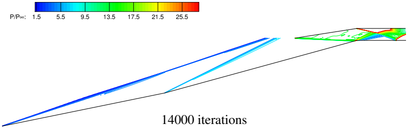
10000 iterations



12000 iterations



13000 iterations



14000 iterations

Outline

Summary

1. Performed inviscid numerical simulations of a typical mixed-compression scramjet intake.
2. Studied its performance for a range of Mach numbers, angles of attack and cowl deflection angles.
3. At off-design conditions, a set of shock and expansion fans are generated in the intake duct, and they reflect between the duct walls.
4. It is found that the maximum pressure recovery is obtained at lower Mach number with weaker shock waves, and the capture mass flow rate is maximum at higher Mach numbers.
5. As the cowl angle is increased, the maximum kinetic energy efficiency is obtained at Mach numbers lower than the design point.
6. At zero velocity initialization, intake starts with deflection of cowl.

Thank you...