The Swala Concept – Ramjet Thrust at Subsonic Speeds

It is correct to say that it is widely believed that ramjets have no significant thrust at subsonic speeds. Wikipedia, for instance, in its article on the subject, states that 'Ramjets generally give little or no thrust below about half the speed of sound, and they are inefficient (less than 600 seconds) until the airspeed exceeds 1,000 kilometres per hour (280 m/s; 620 mph) due to low compression ratios.'

However, while ramjets are certainly inefficient at subsonic speeds, it does not prevent them from generating useful thrust. In the case of the Swala launch concept this thrust, combined with the acceleration provided by a linear induction motor and the lift from the vehicle's aerofoil, enables it to overcome drag – the only restraining force remaining - and lift off from its carriage. Thereafter, given sufficient fuel, its ramjets will enable the vehicle to accelerate away.

The following calculation gives an estimate of the thrust in kiloNewtons (kN) that will be generated by the twin 0.75m diameter ramjets postulated for the Swala vehicle, when accelerated to 400km/h and 600km/h. The key figures here are the values for the specific impulse (Isp), a measure of the particular thrust at a given speed. Data on the Isp of sub-sonic ramjets is not readily come by, but three sources have been located. One is from 'A Ramjet Primer' by the late Glenn Olson - http://www.456fis.org/RAMJET_PERFORMANCE_PRIMER.htm.

This has the following table:
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Mach No.	km/h	Isp Seconds
0.2	249	223
0.3	374	218
0.4	498	250
0.5	623	326
0.6	747	440
0.7	872	533
0.8	996	625
0.9	1121	715
1.0	1245	810

A second source was derived from data supplied by the Smithsonian Air and Space Museum, in the form of a 1948 NACA paper recording subsonic ramjet data derived from wind tunnel work. A montage of the graphs showing the subsonic Isp values derived from them (a parameter that did not exist at the time these graphs were created) is provided at the end of this note.

Finally, in the section of examples of subsonic use, data from the Hiller Hornet helicopter is used to obtain an estimate of the Isp given by its ramjets at its lift-off, a value of about 300 seconds.

From these sources it is assumed conservatively that the ramjet Isp at 400km/h would be about 230 seconds and at 600 km/h would be about 300 seconds. (Solid fuel rocket motors have Isp values of 250 – 290 and liquid hydrogen-liquid oxygen rockets of about 450).

The calculation of the thrust, using the relationship Force (N) = gravity (m/s^{-2}) x Isp (seconds) x fuel flow (kg/s) is as follows:

Calculation of Thrust

Parameter	Unit	Value	Value
Speed	km/h	400	600
Speed	m/s	111	167
Inlet diameter	M	0.75	0.75
Inlet area	m^2	0.44	0.44
air volume	m^3/s	49.09	73.64
air density	kg/m^3	1.194	1.194
air mass	kg/s	58.62	87.93
fuel/air ratio	(stoichiometric)	0.06	0.06
fuel mass	kg/s	3.52	5.28
Isp	S	230	300
Thrust	kN	7.9	15.5
Total thrust (2 ramjets)	kN	15.9	31.0

The calculation of the drag that has to be overcome by this thrust draws upon a paper to be found at the following location:
https://repositories.lib.utexas.edu/bitstream/handle/2152/33072/PN_261_Caprio.pdf?sequence=1

This work – 'Linear Electric Motors for Aerospace Launch Assist' - arose from a request by NASA to the University of Texas to determine the suitability of the linear induction motor and linear synchronous motor (LIM and LSM) for launching aerospace vehicles, presumably powered by ramjets or scramjets, by accelerating them down a LIM or LSM track at 7g to 300m/s (1080km/h). Their methodology is used here for the case of a Swala vehicle with a drag coefficient of 0.3 and a frontal area of 4.5 square metres that is accelerated to 111m/s (400km/h) and 167m/s (600km/h) down a LIM track at 1g.

Calculation of Drag

Maximum launch velocity, m/s (v)	111	167	400 km/h and 600 km/h
Frontal area, m^2 (a)	4.5	4.5	From front outline diag., pixels to sq. cms.
Assumed drag coefficient (c)	0.3	0.3	See note below
Air density, kg/m^3 (ρ)	1.19	1.19	20 deg C and 1 atm
Acceleration, m/s^{-2}	9.8	9.8	1g constant acceleration assumed
Time, s	11.3	17.0	Calculated launch duration
Distance, m	629	1423	Calculated launch distance
Calculated drag force, kN	10.0	22.4	From the drag eqn.: $a \times 0.5c \times \rho \times v^2/1000$

The drag coefficient is the most debatable part of the calculation; the figure of 0.3 is an arbitrary one. Wikipedia gives examples of 30 motor cars that have an average value of 0.28, and of ten aircraft with an average value of 0.037.

This wide divergence makes it necessary to approach the question from the other side. For the drag to equal the net 15.9kN of thrust that the twin Swala ramjets will generate at 400km/h (that is, sufficient drag to stall the vehicle), the drag coefficient would have to be about 0.47. To equal the roughly 31kN generated at 600km/h it will need to be about 0.42. As the coefficient is likely to be more like an aircraft than a car, say under 0.1, then there should be ample thrust remaining after allowing for drag for the Swala vehicle to accelerate forward off its carriage. Specifically, at a value of 0.1 it would be 13kN and 24kN respectively.

Practical examples of the utility of subsonic ramjet thrust

The perseverance of the idea that no useful thrust can be obtained from ramjets much below Mach 1 is probably because almost all recent examples of their use have involved accelerating the vehicle to at least that before their ignition. For example, the ramjets used in missiles like the Bomarc and the Talos employed solid fuel rockets (with Isp values of about 280*)* to bring them up to Mach 1, while those in aircraft like the SR-71 Blackbird used gas turbines.

However, it is relatively easy to accelerate the rotors of small helicopters to tip speeds at which small ramjets mounted there will start to give significant thrust, and so the examples below are principally from this field.

1947. **The Little Henry** helicopter had ramjets on its rotor tips which started delivering thrust at velocities of 45 m/s, or about 160 km/h and lifted a total of 270kg.
https://www.youtube.com/watch?v=qs7WlNrHRmA

1949. **The LeDuc 010** aircraft, developed by Rene Leduc in France, was the first powered only by a single ramjet, and was launched from atop a conventional aircraft at 320 km/h. To quote from Wikipedia 'it demonstrated the viability of the ramjet as an aviation powerplant, with a rate of climb of 40 m/s (7,900 ft/min) to 11,000 metres (36,000 ft), exceeding that of the best jet fighters of the time'. The aircraft reached a top speed of Mach 0.85, at which point the approaching 'sound barrier' caused enough loss of control to discourage further acceleration.

https://www.youtube.com/watch?v=McOJbmC6-04

1953 **The Hiller Hornet** resembled the Little Henry helicopter and lifted a total of 490kg when its rotors were travelling at a peripheral speed of 340 km/h, generating 2 x 178N of thrust.
https://www.youtube.com/watch?v=NX-911v7BHk

1957: **The Kolibrie helicopter** – this Dutch invention had a take-off weight of 650kg with ramjets that were ignited at 70 rpm (the rotor was 9.95m diameter, giving a tip speed of 130km/h).

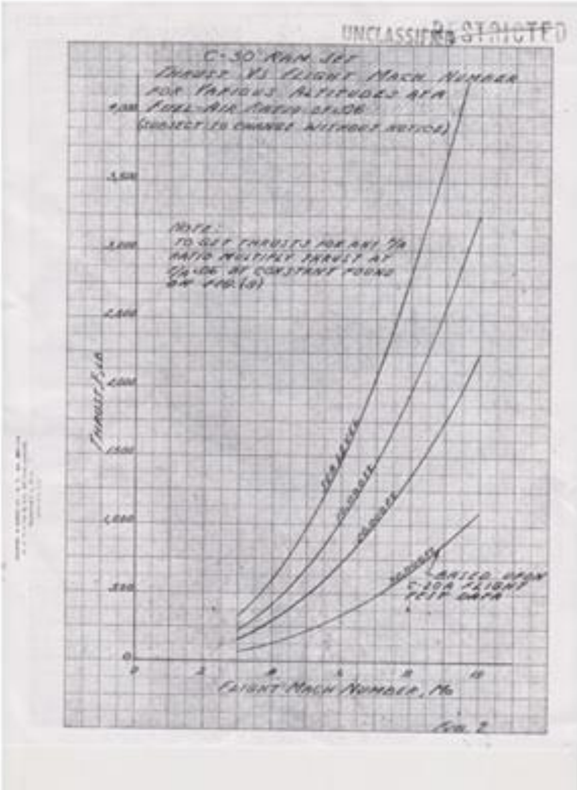
https://www.youtube.com/watch?v=2b-h8NgsieQ

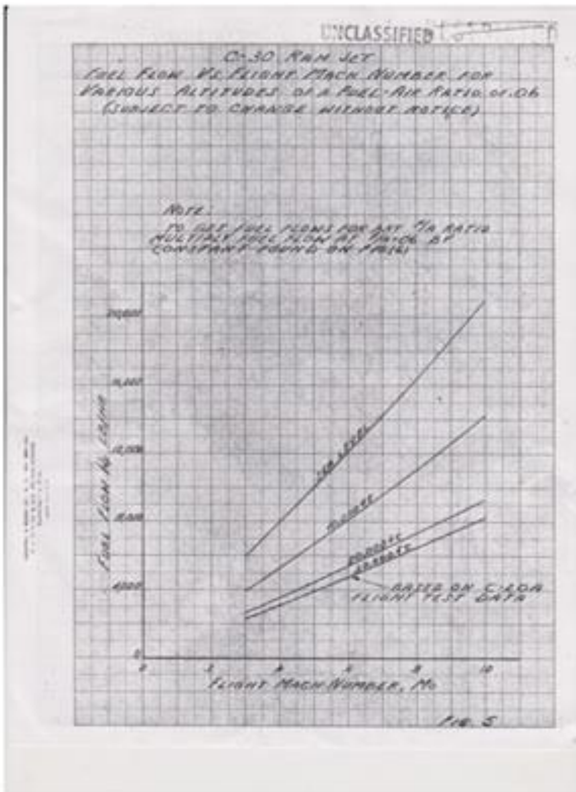
https://youtu.be/hI2cvaAx8j4

From the Hiller Hornet data, it is possible to derive the Isp of its ramjets at lift-off speed:

Ramjet diameter (+/-6 inches)	Mm	150
Lifts off its 290kg at a tip speed of -	km/h	340
Or	m/s	94.4
giving an air volume entering of	cu m/s	1.67
Air density	kg/cu m	1.20
Air mass	kg/s	2.00
Fuel:air ratio		0.06
So fuel consumption	kg/s	0.12
Thrust given as (2 x 178)	N	356
Thrust N is given by	N	g x Isp x fuel use
So Isp =	S	Thrust/(g x fuel use)
Isp =	S	**302**

It has to be concluded that at 400km/h there is greater thrust from a ramjet than there is from the solid fuel motors conventionally used to bring ramjets up to operational speed.





C-30 Ramjet Isp values vs Mach Number — Smithsonian Data from 1948