ATKINS

The *Bloodhound* Supersonic Car: Innovation at 1,000 mph

01/11/14

Introducing the Presenters

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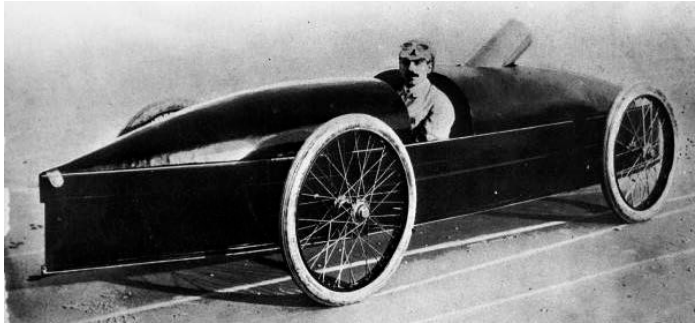
Setting a Land Speed Record

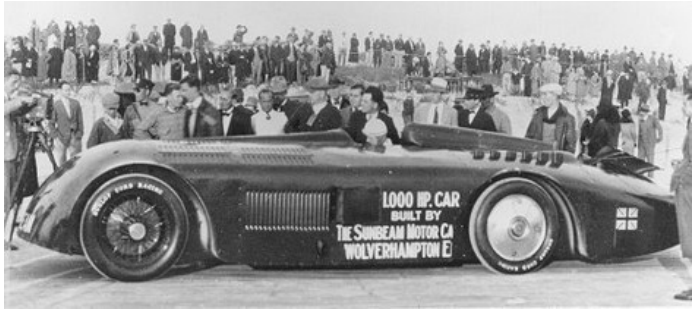
- Certified by Fédération Internationale de l'Automobile (FiA)
- Multiple LSR Categories
  - i.e. Wheel Driven, Electric, Motorcycle
- Outright World Land Speed Record
  - No engine or drivetrain restrictions
  - Driver must be in full control
  - Must have 4 wheels
  - Speed over 1 mile with flying start
  - Average of 2 attempts within 1 hour
- Current Record:
  - Thrust SSC – 1997 – 763.035 mph

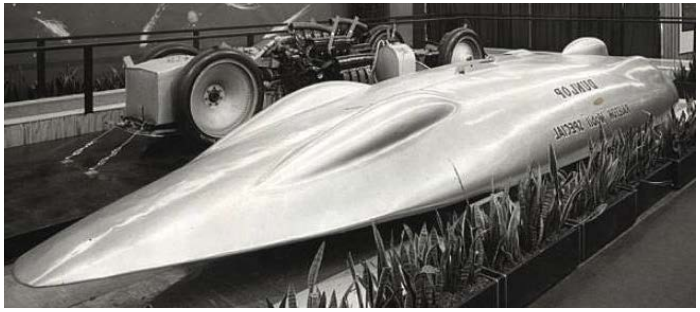
Thrust SSC lays shock waves across the Black Rock Desert, Oct 15th 1997

Key Milestones in History of LSR

- 1898 – Jeantaud Duc – 57.7 mph
  - Earliest recorded land speed attempt
  - Electric coach piloted by Gaston de Chasseloup-Laubat
- 1906 – Stanley Rocket – 127.7 mph
  - First record over 200 km/h
  - Steam powered car piloted by Fred Marriott
- 1927 – Sunbeam 1000 hp – 203.8 mph
  - First record over 200 mph
  - Internal combustion car piloted by Henry Segrave
- 1935 – Blue Bird – 301.1 mph
  - First record over 300 mph
  - Internal combustion car piloted by Malcolm Campbell
- 1947 – Railton Mobil Special – 394.19 mph
  - Last record without jet/rocket propulsion
  - Internal combustion car piloted by John Cobb

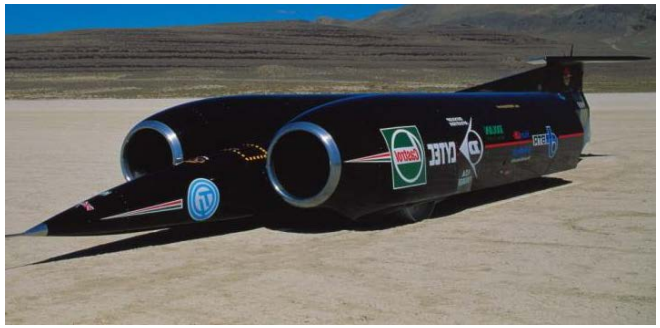






Key Milestones in History of LSR

- 1963 – Spirit of America – 407.4 mph
  - Marks shift to jet powered propulsion
  - Turbojet powered car piloted by Craig Breedlove
- 1965 – Spirit of America Sonic 1 – 600.6 mph
  - First record above 600 mph
  - Turbojet powered car piloted by Craig Breedlove
- 1970 – Blue Flame – 630.5 mph
  - First record above 1000 km/h
  - Rocket powered car piloted by Gary Gabelich
- 1997 – Thrust SSC – 763.5 mph
  - Standing record to this day
  - First supersonic car
  - Turbofan powered car piloted by Andy Green
- 2015 – Bloodhound SSC – 1050 mph target
  - Spiritual successor to Thrust SSC
  - If successful, first record above 1000 mph

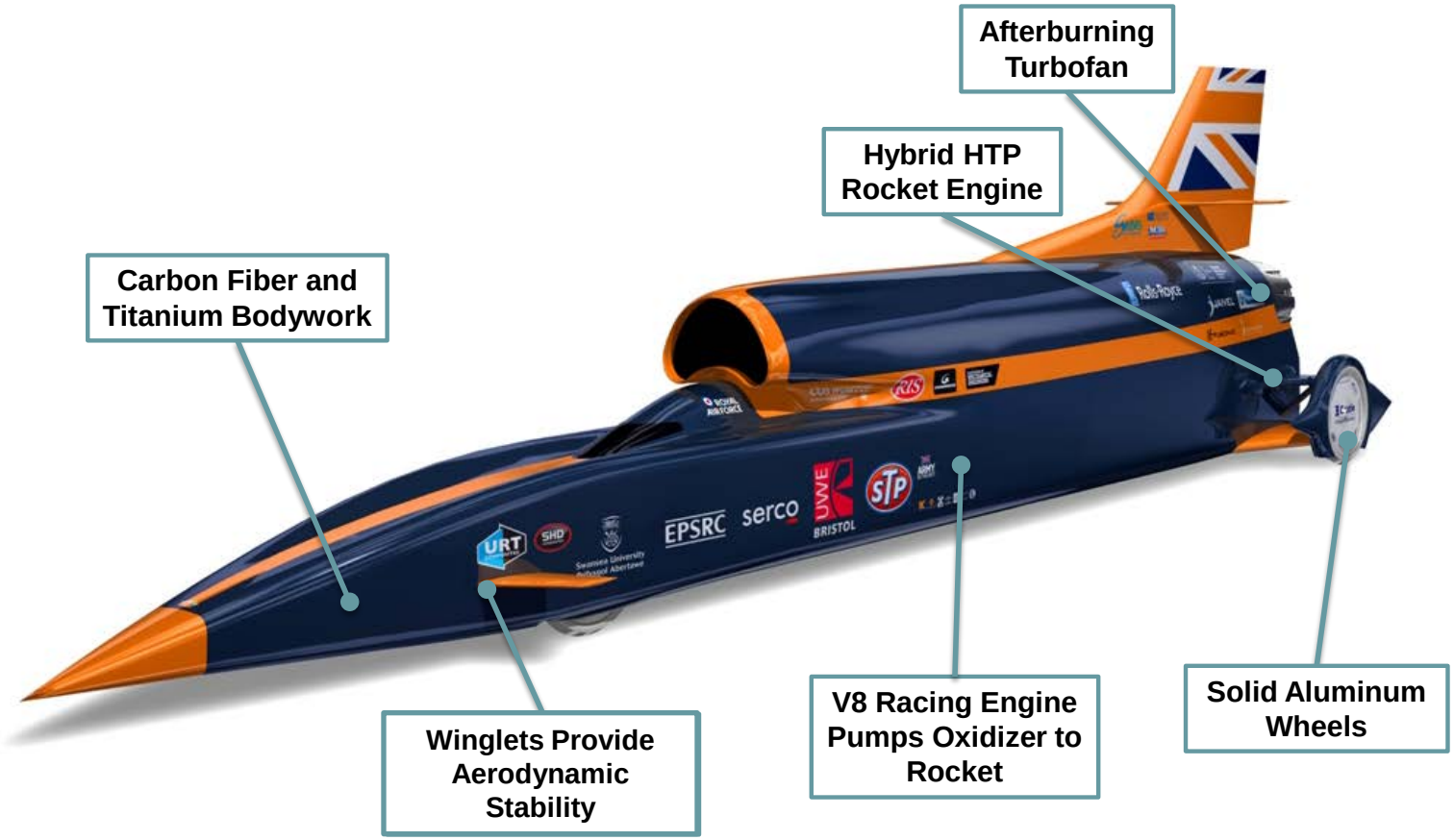


Bloodhound mission

Vehicle	*Weight (kg)*	*Max Power (hp)*	*Average Fuel Consumption (mpg)*	*Turning Circle (ft)*	*Max Speed (mph)*
Toyota Camry	1470	178	35.0	37	131
Ferrari 458	1400	605	20.0	40	205
Bloodhound	~7800	135,000	0.04	788	1050

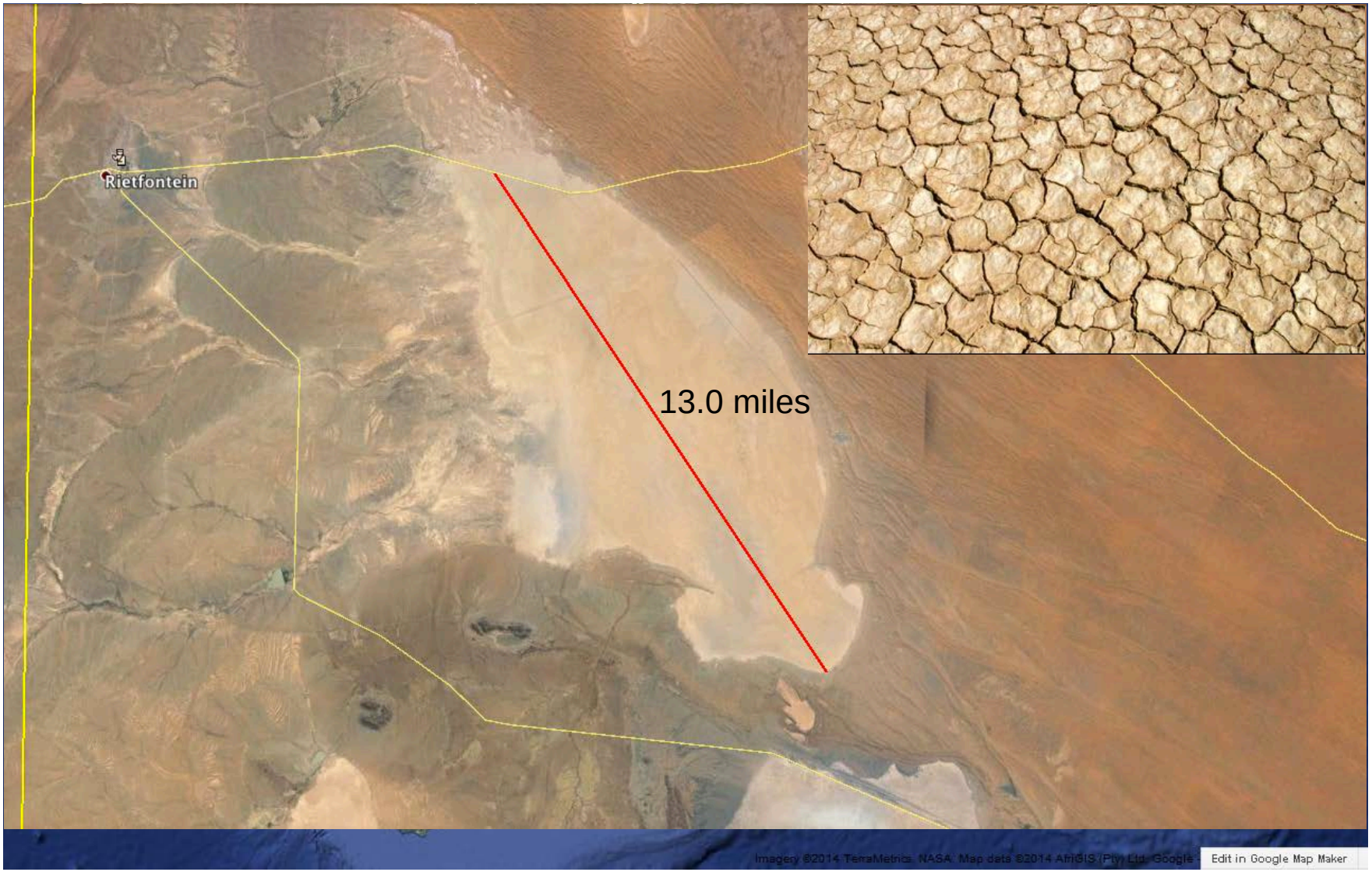
Bloodhound mission

- To extend the world land speed record set by Thrust SSC in 1997 (763.035 mph)
- Raise the record to 1000mph.



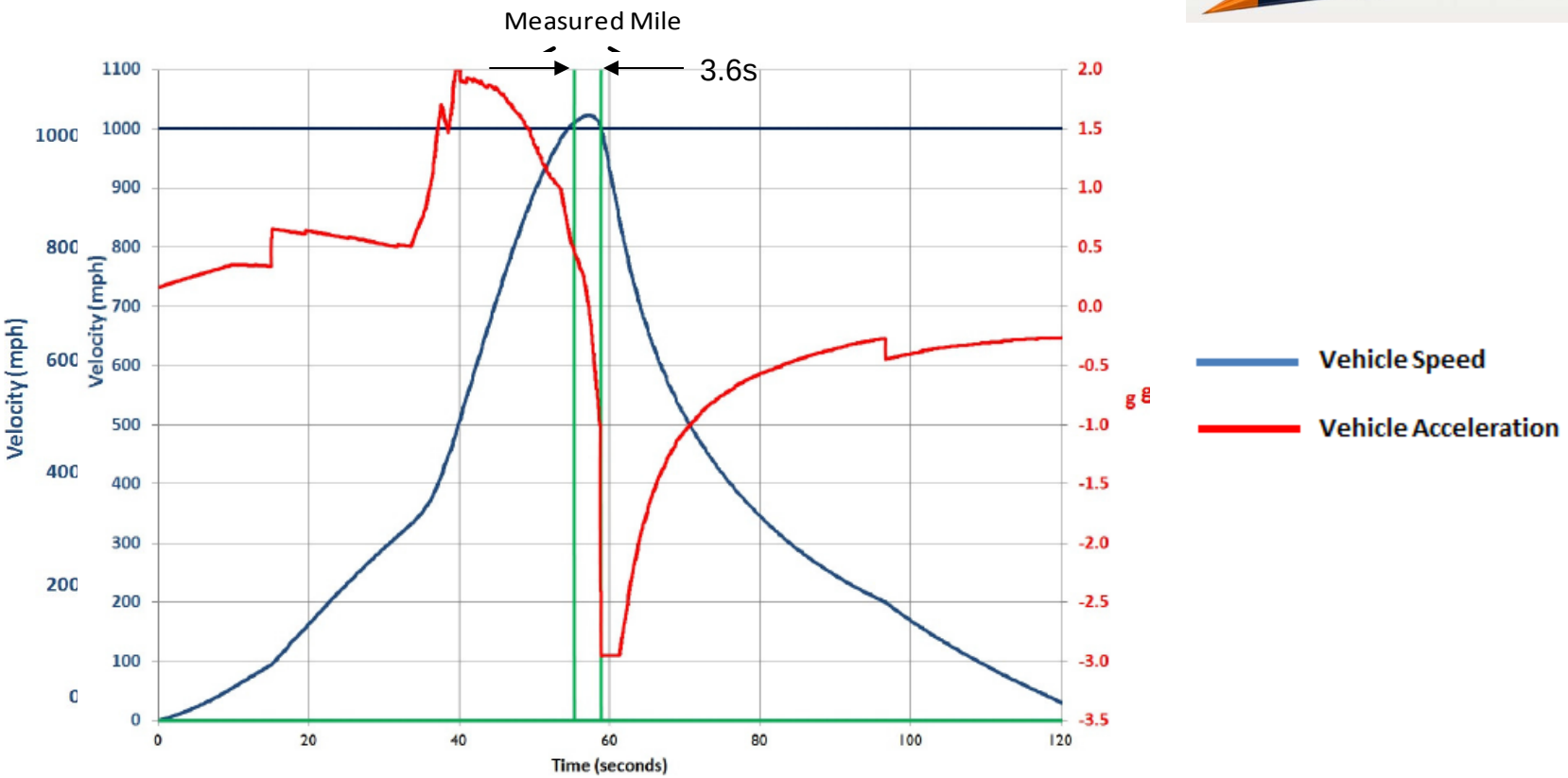
Bloodhound mission

- Attempt at Hakskeen Pan, Northern Cape, South Africa



Bloodhound mission profile

- Cover measured mile at 1000mph
- Constrained by 12 mile course length
- Complete reciprocal run within one hour.

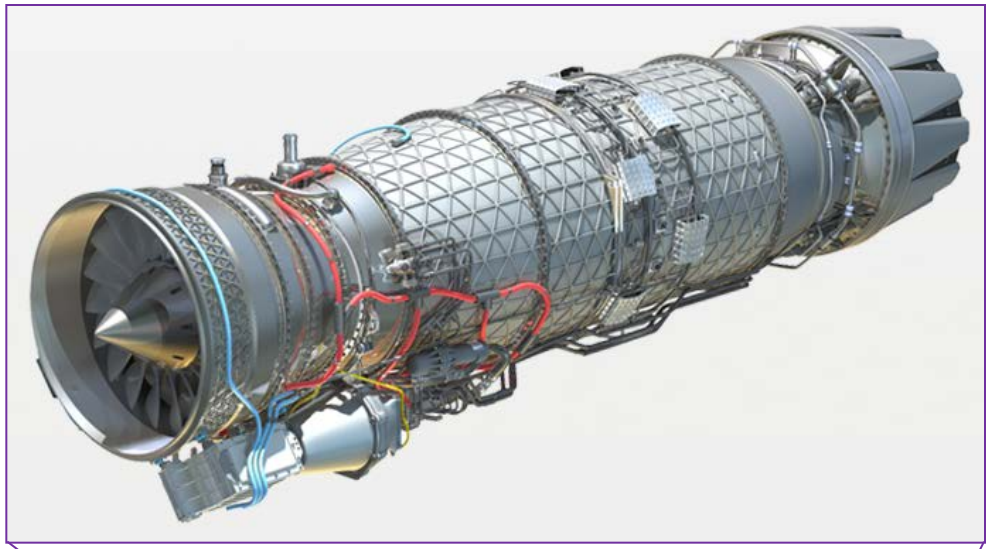


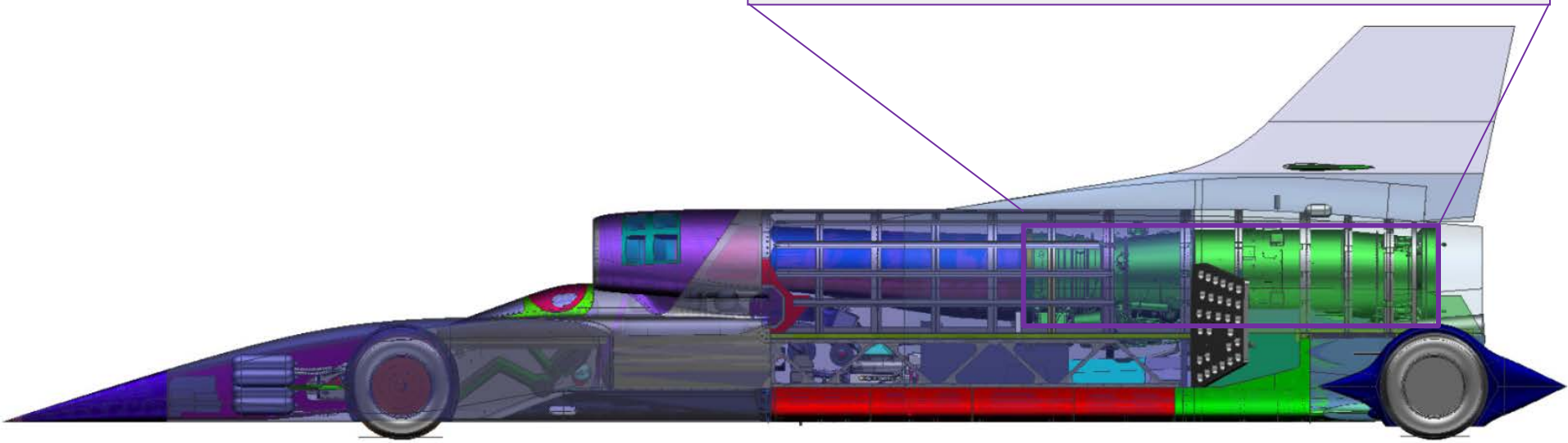
Engines – jet

1x Eurojet, EJ200

T_{dry} = 60kN (13,500lb)
T_{reheat} = 90kN (20,000lb)

Type: 2 power Eurofighter
Fuel: 1040lb (900lb useable)





Engines – jet

Recently installed on the chassis at the workshop in Avonmouth, England.

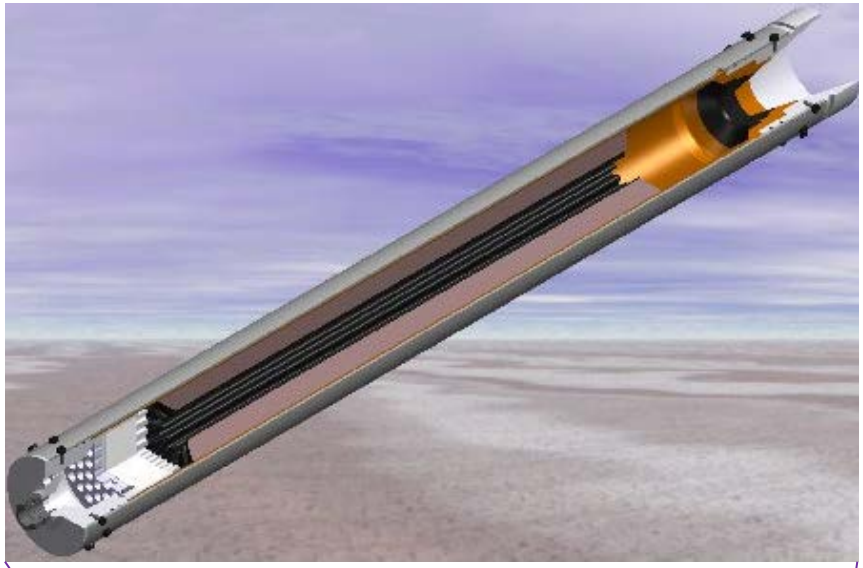
Engines – rocket

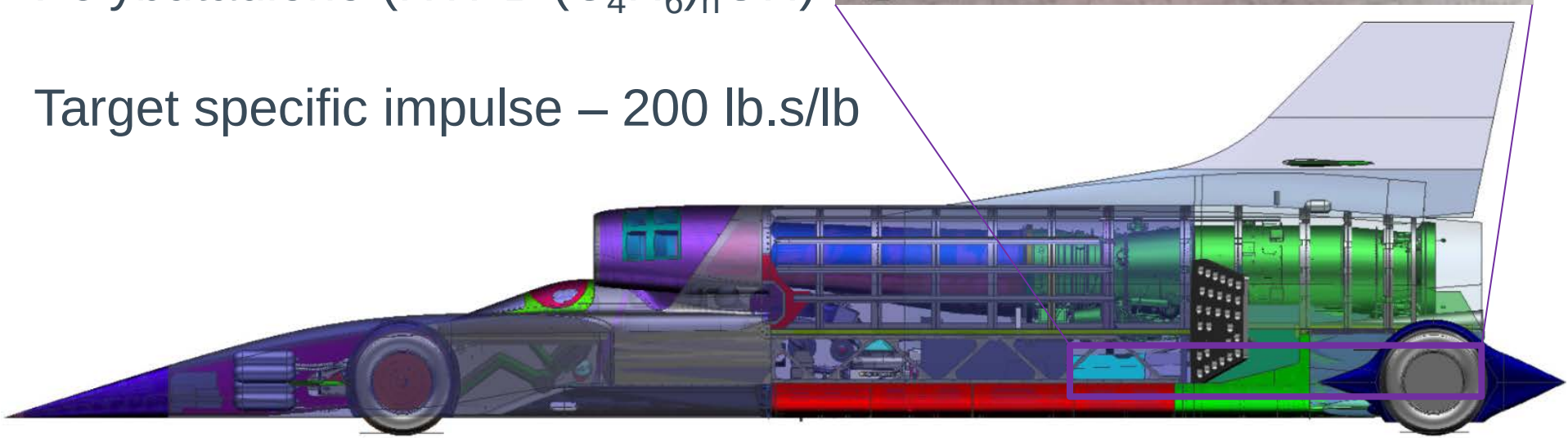
Mounted below the EJ200 engine

T_{max} = 122kN (27,500lb)
T_{av} = 111kN (25,000lb)

Type – Hybrid
Oxidiser - H_2O_2 HTP
Solid fuel - Hydroxyl Terminated Polybutadiene (HTPB $(C_4H_6)_nOH$)

Target specific impulse – 200 lb.s/lb





Engines – auxiliary power unit

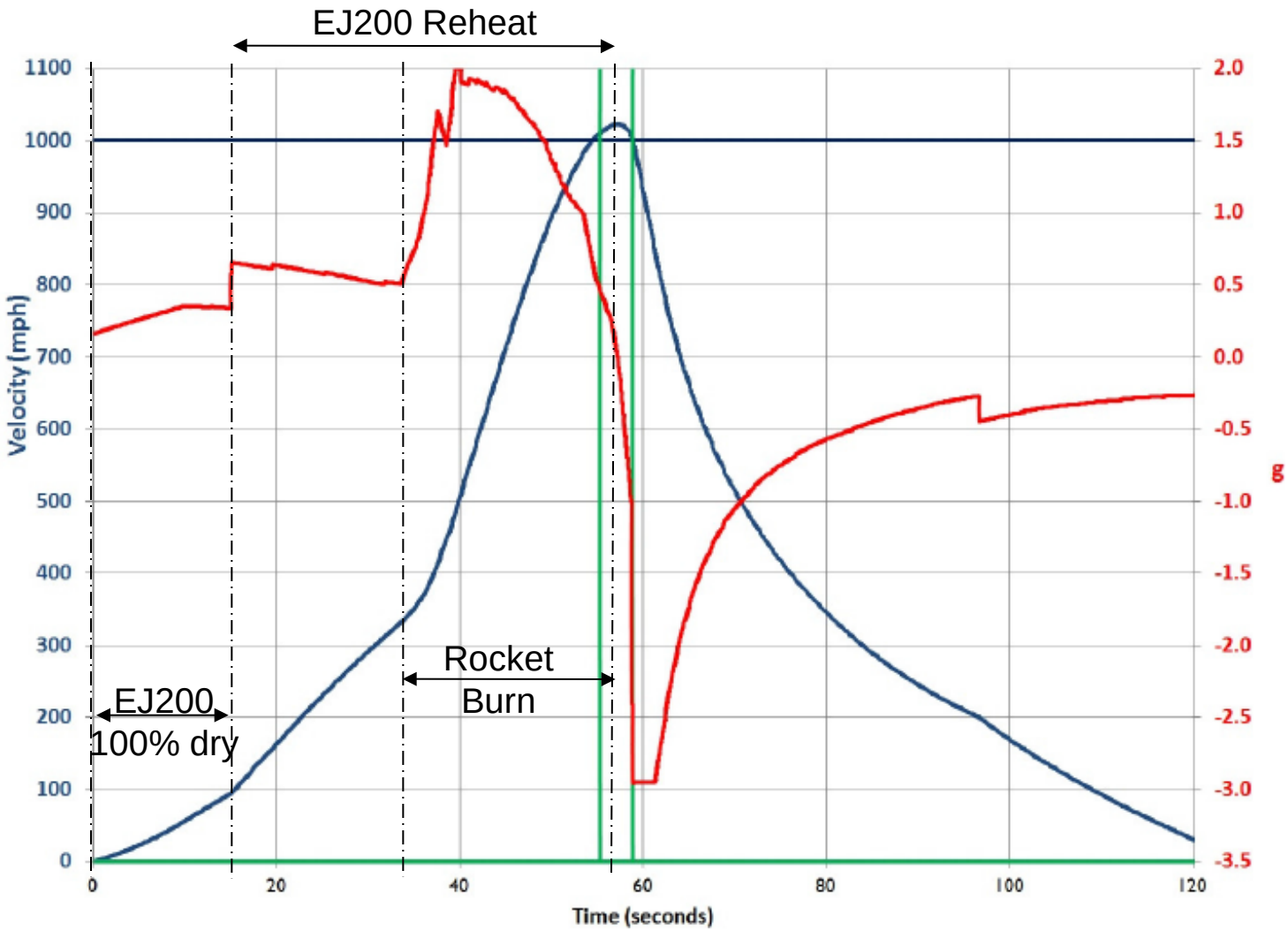
APU supplies power to accessory drive gearbox to:

- Start the EJ200 engine;
- Power electrical equipment;
- Power hydraulic wheel brakes;
- Pump HTP fuel to the rocket.

The APU delivers 800hp -

200hp more than that Ferrari!

Engines – mission sequence



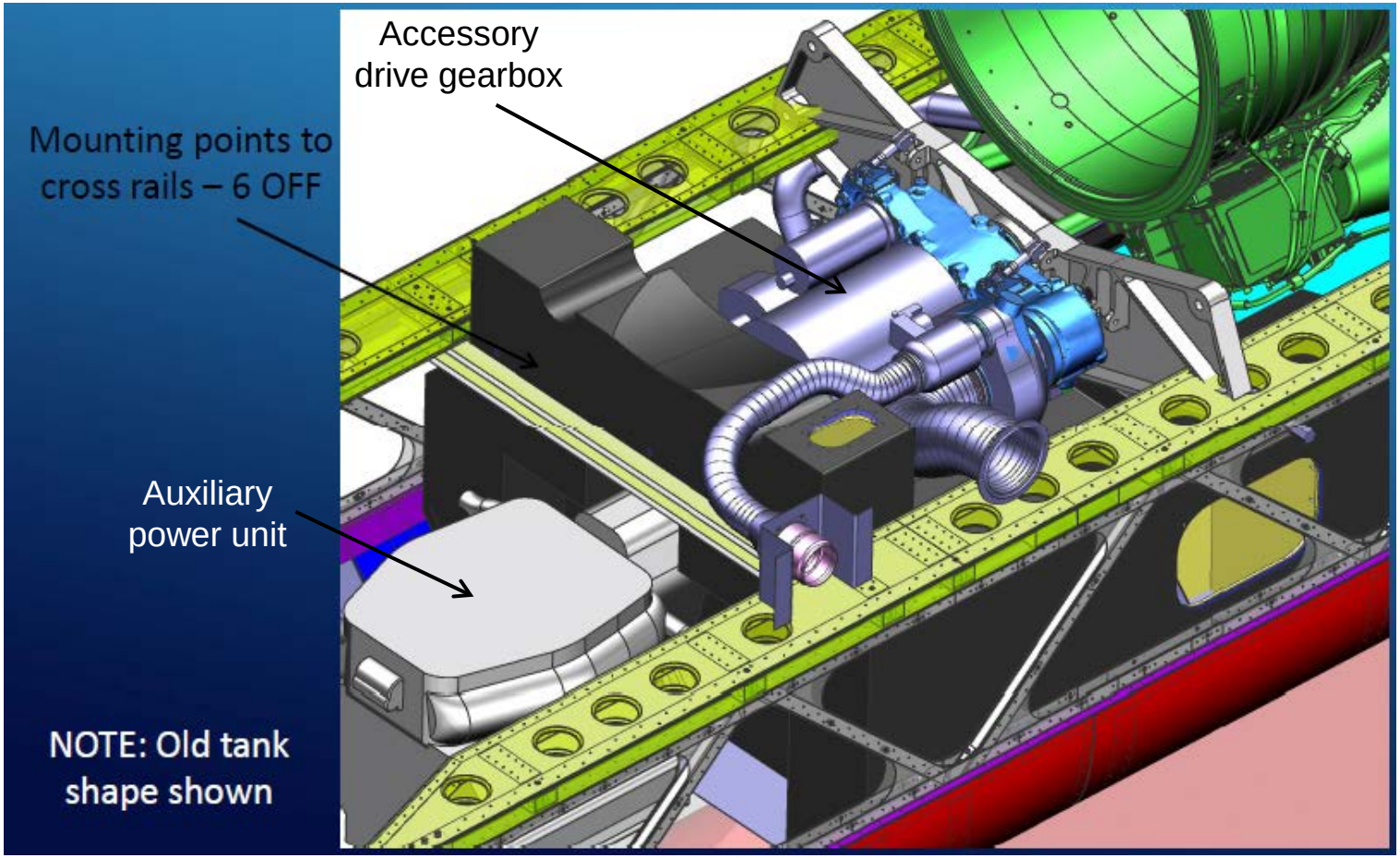
35 s 350 mph +0.5 ‘g’ +1.3 ‘g’ +2.7 ‘g’

EJ200 reheat engage EJ200 engine engaged up to 100% dry thrust

Systems - fuel

The jet fuel (Jet A1) system has a capacity of:

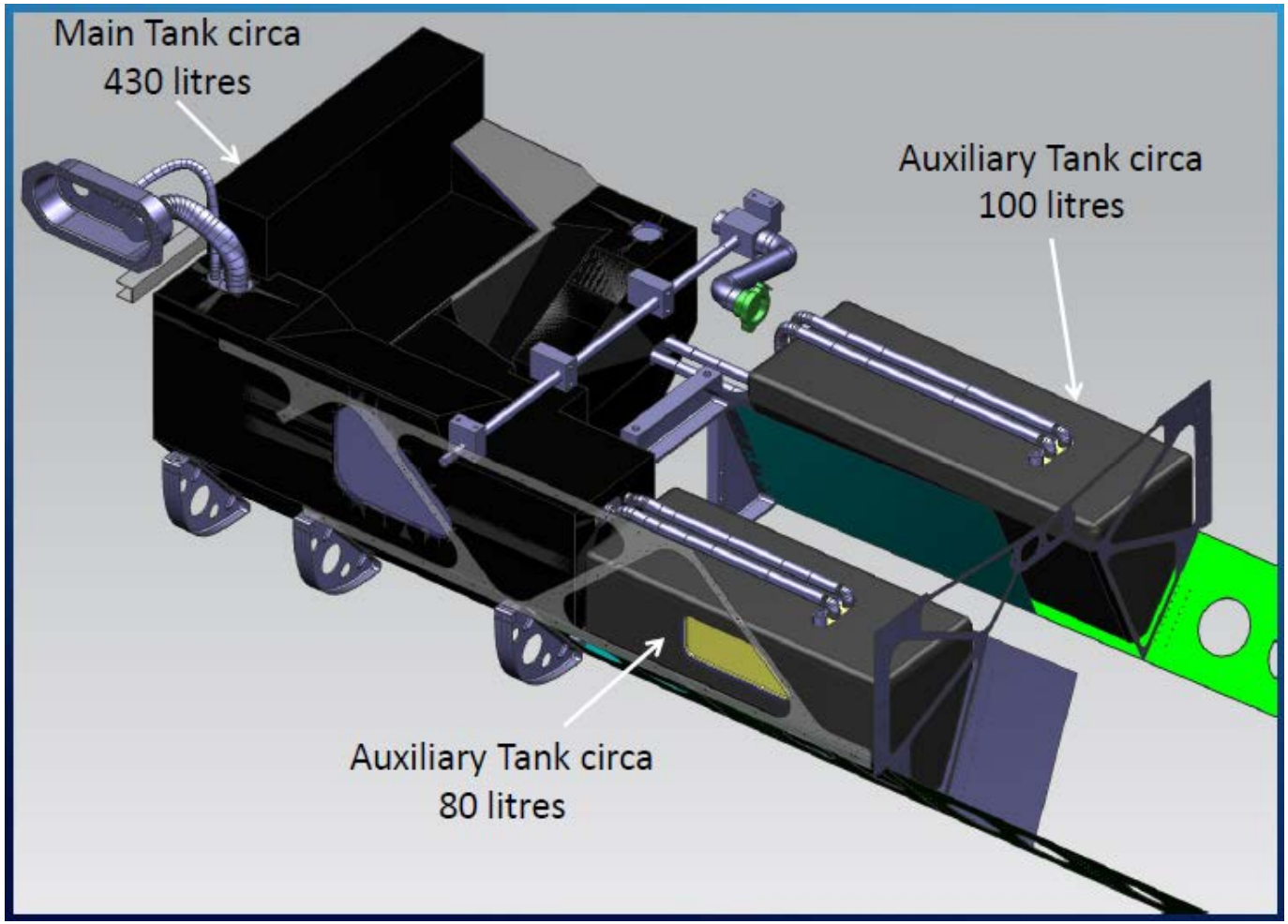
- Main tank, 730lb



Systems - fuel

…and further capacity of

- Auxiliary tanks, 170lb and 140lb

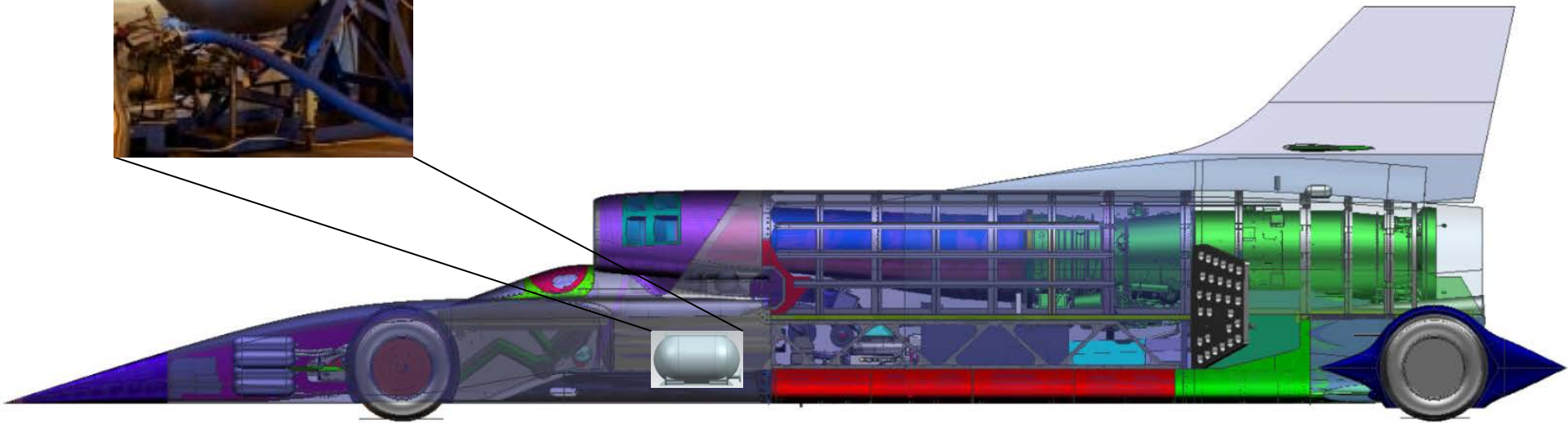


Systems - fuel

The rocket fuel tank has a capacity of 2900lb HTP

Pumped by APU at 110lb/s for 20s burn.

Construction – stainless steel



Systems - braking

Having reached 1050mph, the car has 660MJ of energy, to be dissipated in 60s: an average of 15,000 bhp.

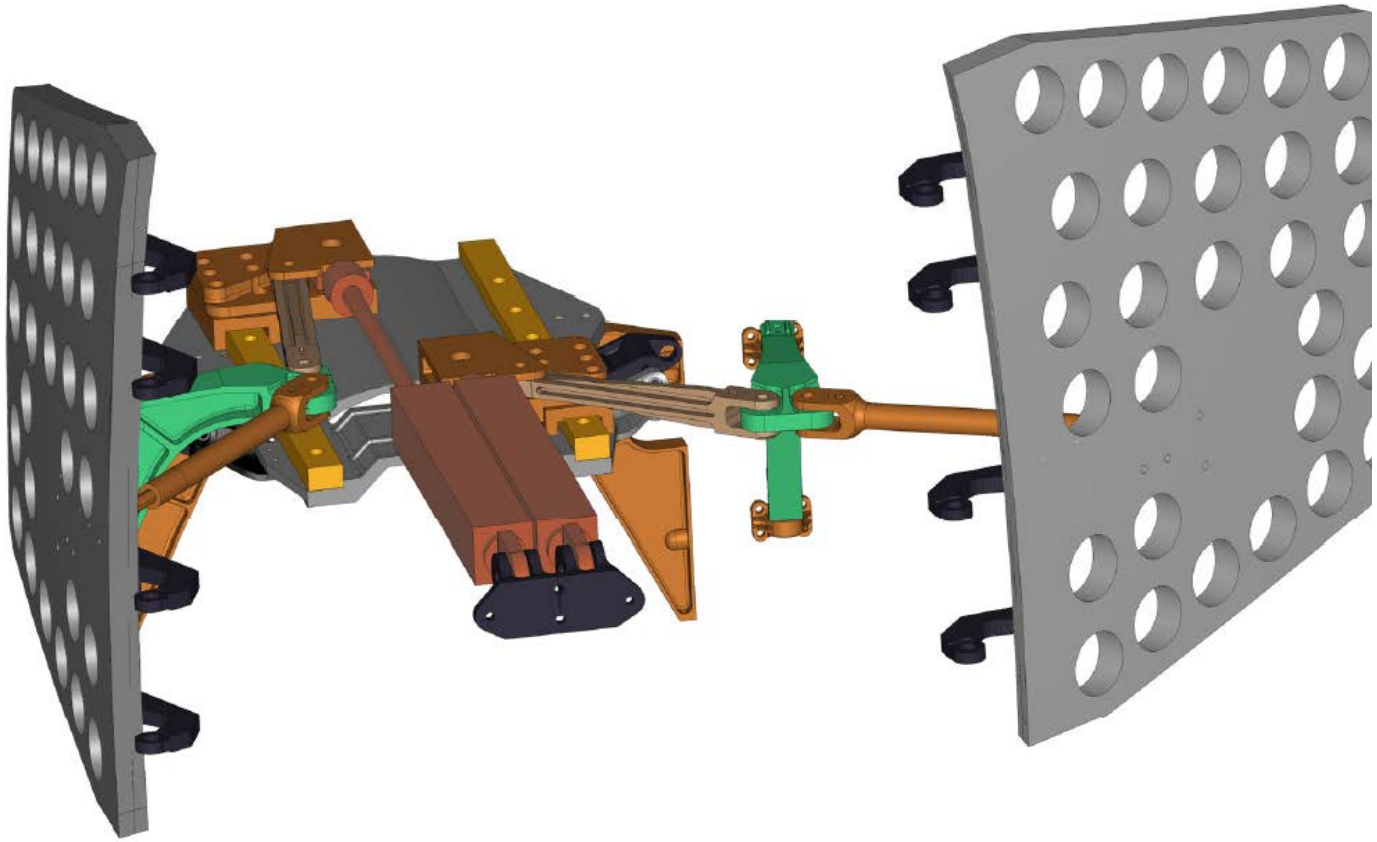
The braking system comprises three components:

- Airbrakes
- Parachutes (if needed)
- Wheel brakes

In addition, the drag of the car is effective in decelerating from the highest speeds – 15 tons at M=1.4 (96,000 bhp).

Systems - airbrakes

Airbrakes applied at 800mph, but designed for 1000mph:



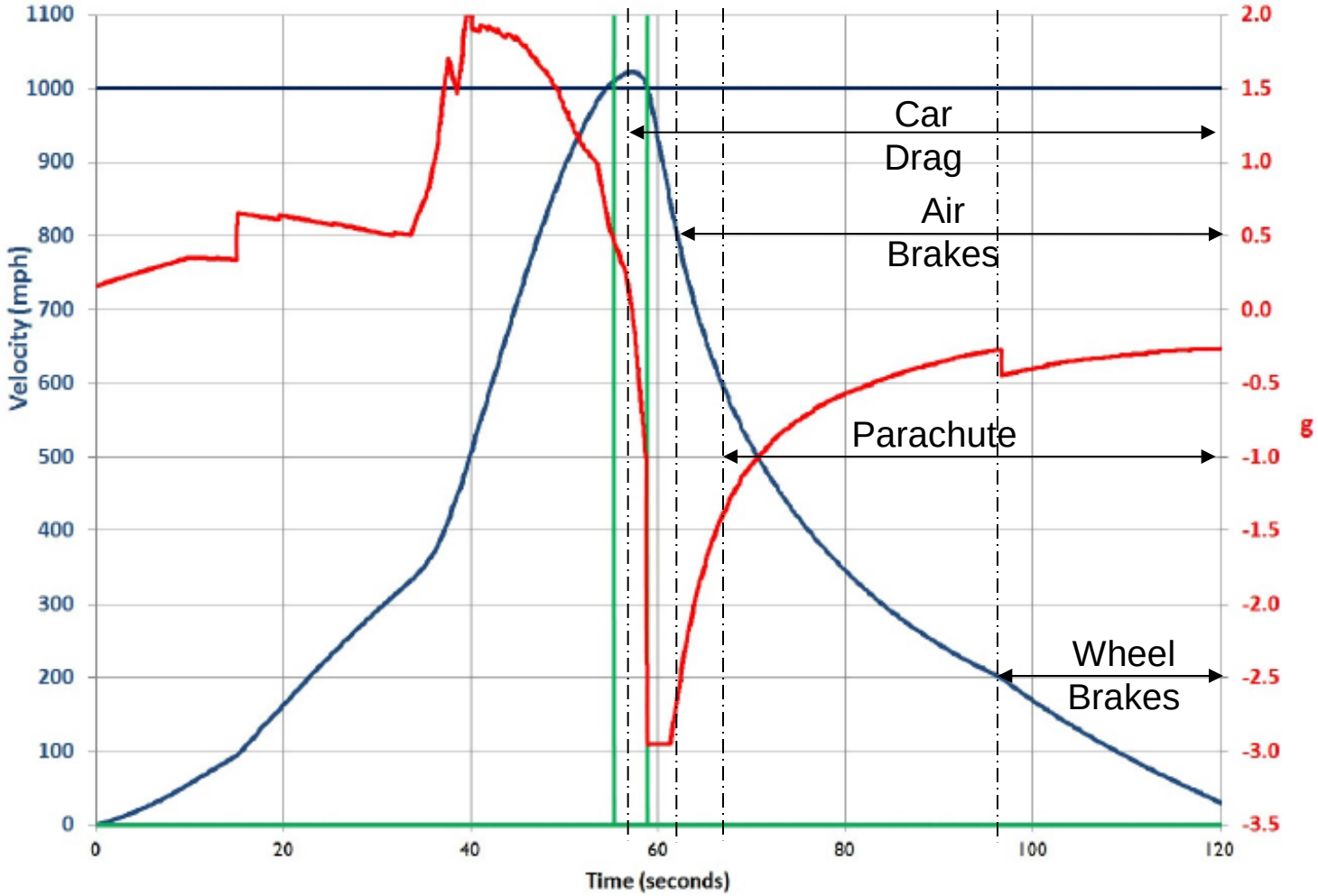
Time (s)	Speed (mph)	Brake Angle (º)	Brake Force (lbf)
6.5	1000	45	26500

Systems – braking safety

Braking options:

- Airbrakes, one parachute and wheel brakes stop car in <4.5 miles;
- Second parachute available if necessary;
- If the airbrakes fail, both parachutes and wheel brakes can stop the car in 4.5 miles;
- If both parachutes fail, airbrakes and wheel brakes will stop the car, but using the overrun distance.

Braking – mission sequence

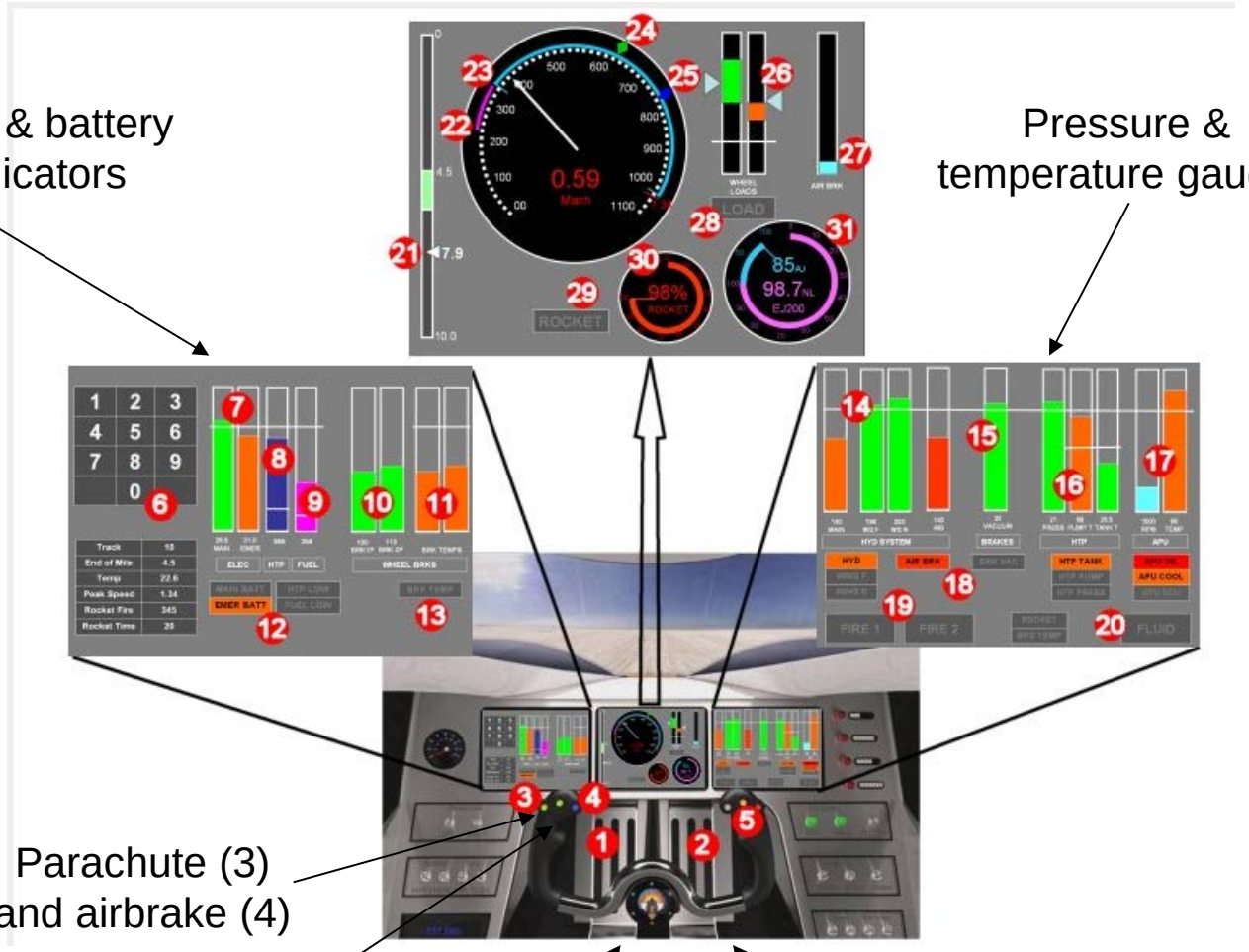


[illegible] s [illegible] mph [illegible] g

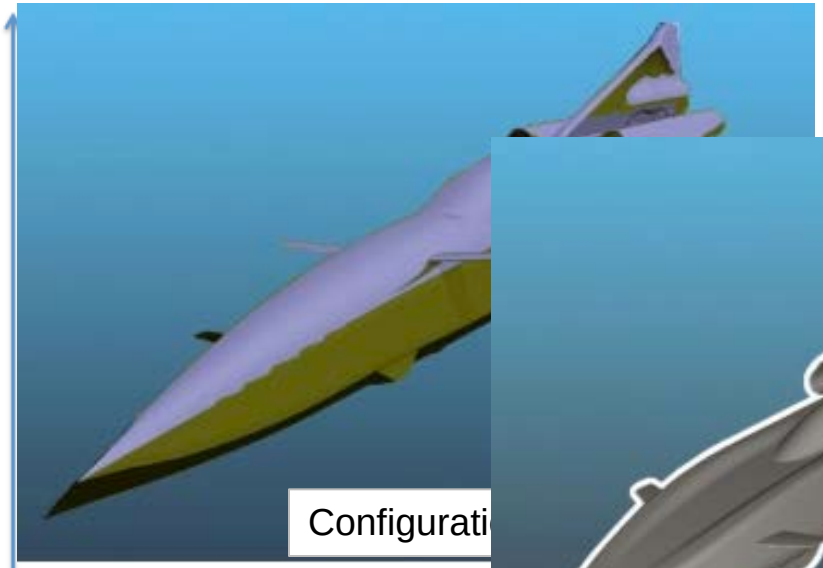
Air brakes deploy (1.5 s) and decreases the angle

Wheel brakes deploy (10 s) and decreases the angle

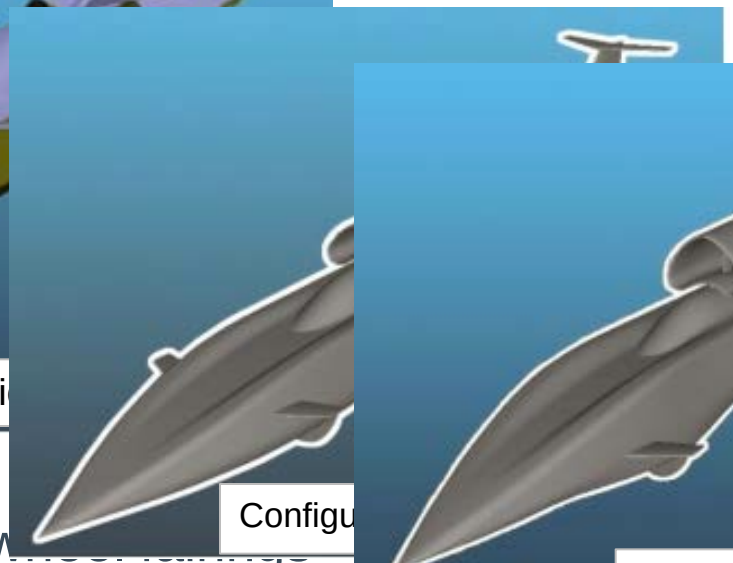
Systems – cockpit



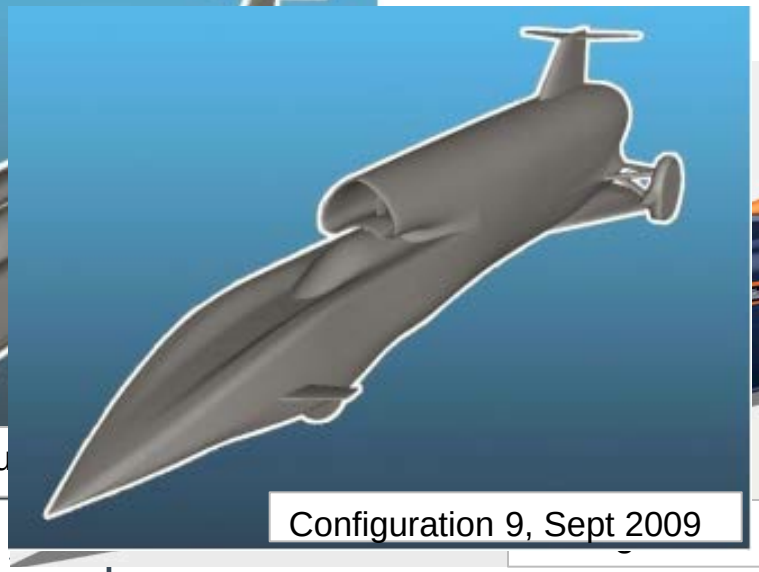
Aerodynamics – car evolution



Twin intakes, large
above jet, no rear



Curved intake,
surfaces, contoured



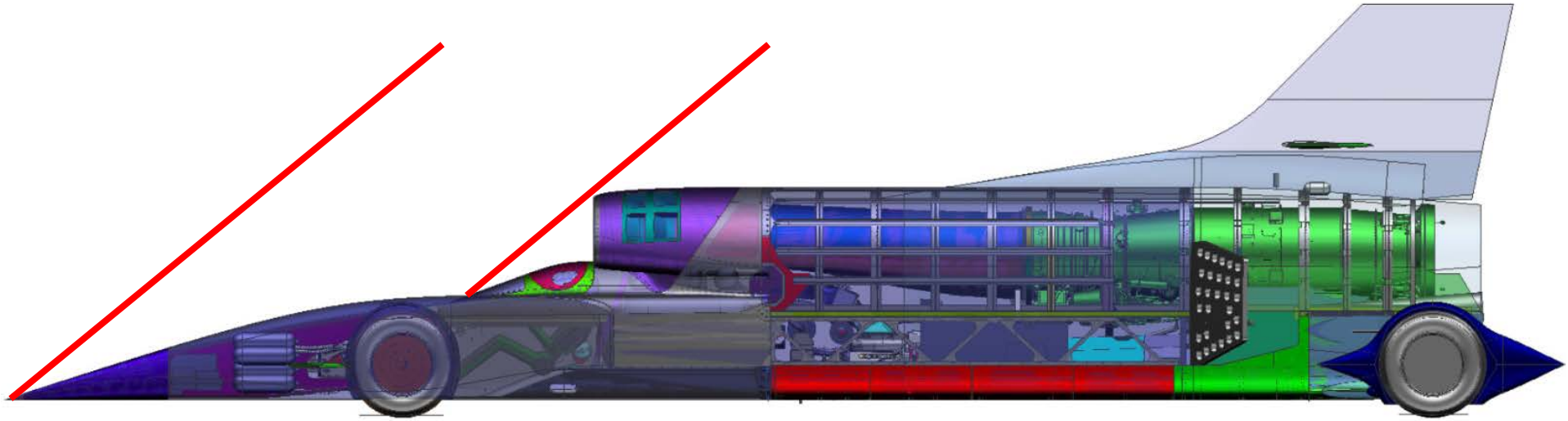
Now jet over rocket. Fin/T-tail
reinstated. Delta strut and
ventral strakes. Contoured body.

12, Aug 2010

Boxy tail replaced by mid-height tail
with dorsal strake. On-going
refinement of body contours.

2007 2008 2009 2010

Aerodynamics – intake compression

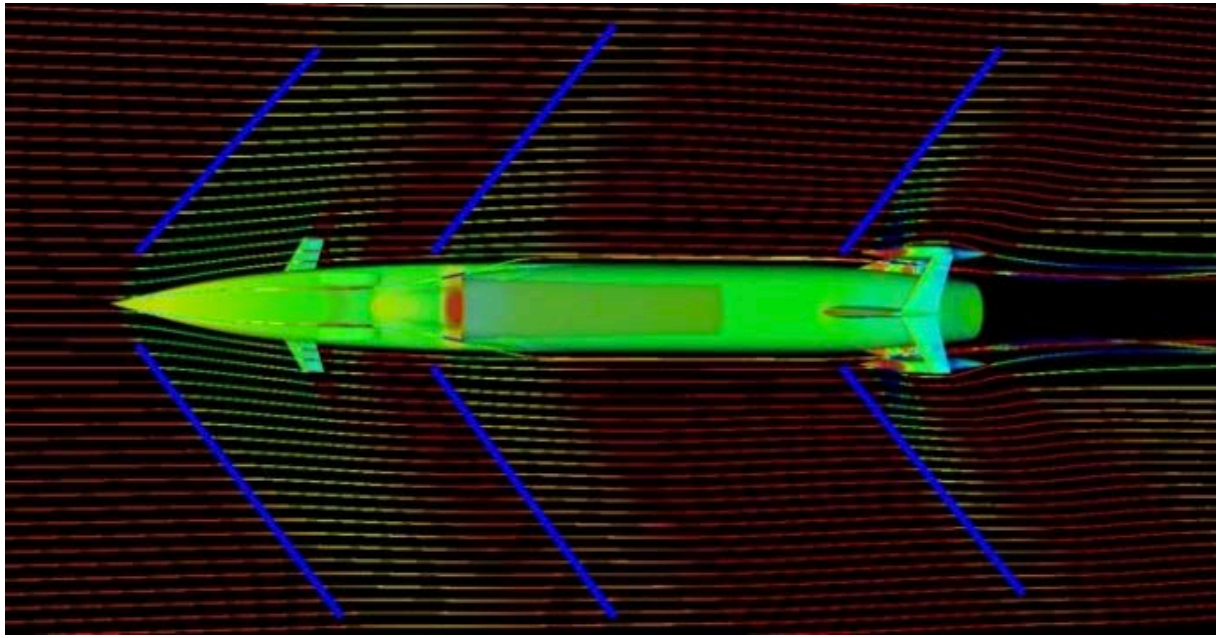


Shock wave angles at M=1.4 (1050mph).

Much CFD on intake design to avoid surge issues (surge margin of EJ200 eroded for increased performance).

Aerodynamics – whole body

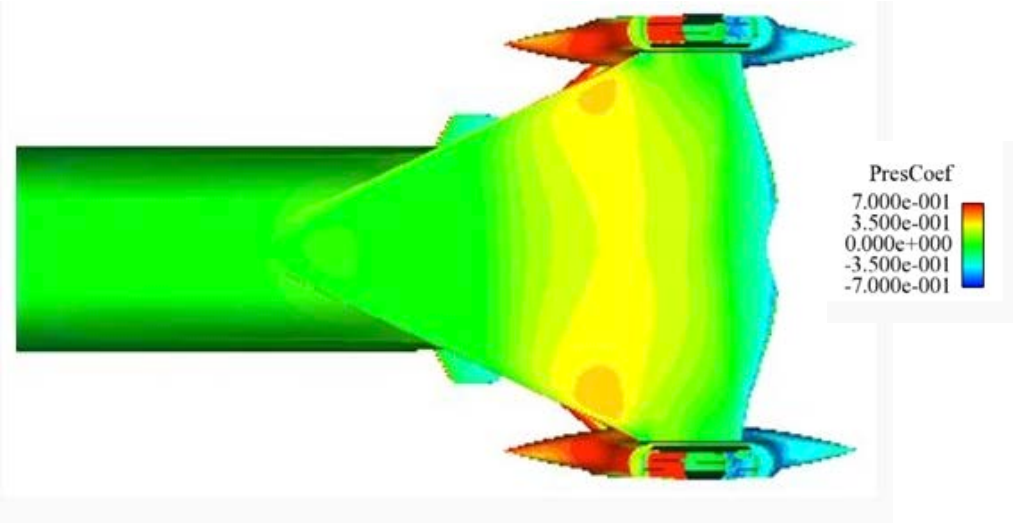
Making the car lift-neutral over the speed range has been a primary goal.

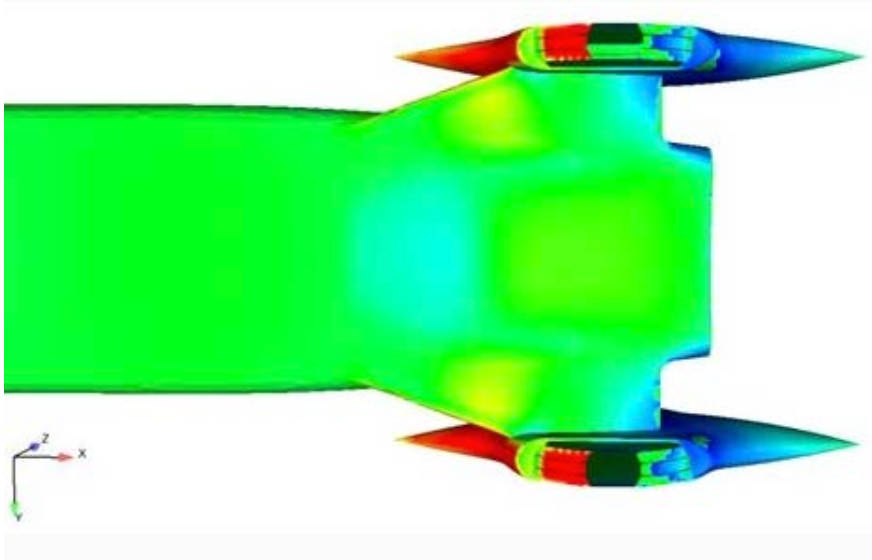


Shock waves at M=1.3 from the nose, cockpit surround and wheel fairings.

Aerodynamics – aft body

Reducing the lift of the aft body at M > 1.0 has been a major challenge – achieved using ventral aerofoils.

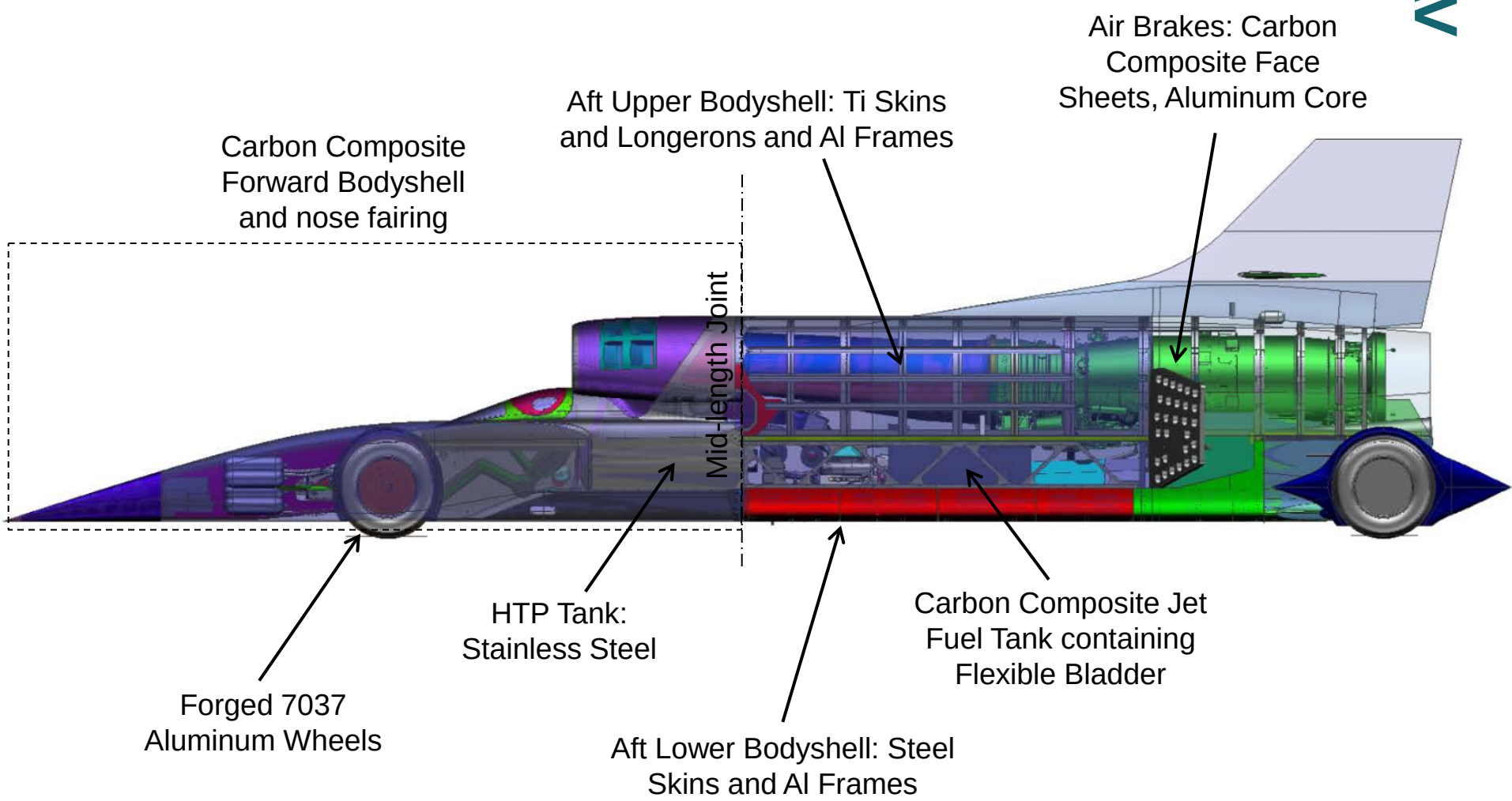




Previous design – $C_p > 0$ over much of underside.

Current design – $C_p = 0$ over much of underside.

Structures - materials



Structures - manufacture

Follows experience in aerospace and motorsport:

•Hand lay-up – labour intensive, but it's a one-off

•Autoclave cure – expensive plant, but not dedicated to *Bloodhound* manufacture.

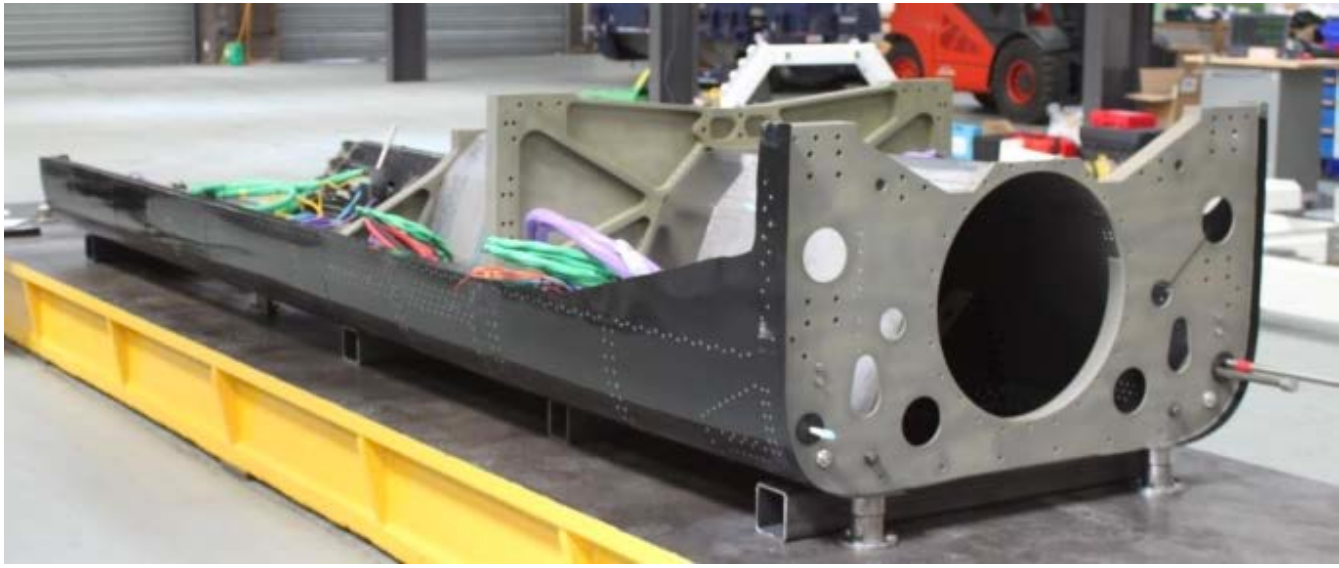
Completion of the cockpit/intake monocoque at URT Group.

Structures - manufacture

Lower chassis in steel sheet with aluminum frames:

- Rivets provide sufficient strength
- Redux bonding adds stiffness.

The complete lower chassis following riveting and bonding.

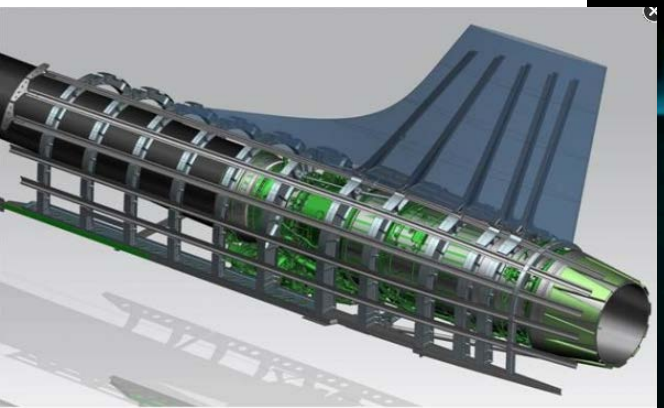


Structures - manufacture

Upper chassis in titanium sheet with aluminum frames and titanium stringers:

- Frames support the EJ200 engine
- Aft, heavy frames support fin.

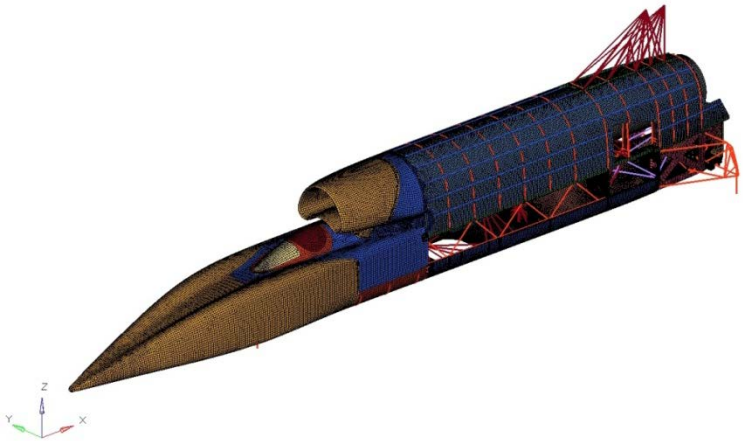
Aluminum frames for the upper chassis, Feb 2014.



Structures - analysis

- Static analysis - ultimate factor of 2.4 for composites
- Fatigue – not considered: short vehicle life; part replacement as required
- Damage tolerance - not considered:
  - Large ultimate factor on plain strength
  - Low number of cycles, limiting damage growth
  - Inspection after test runs, giving opportunity for repair/replace.
- Natural frequencies – minimum frequency requirements to avoid flutter issues.

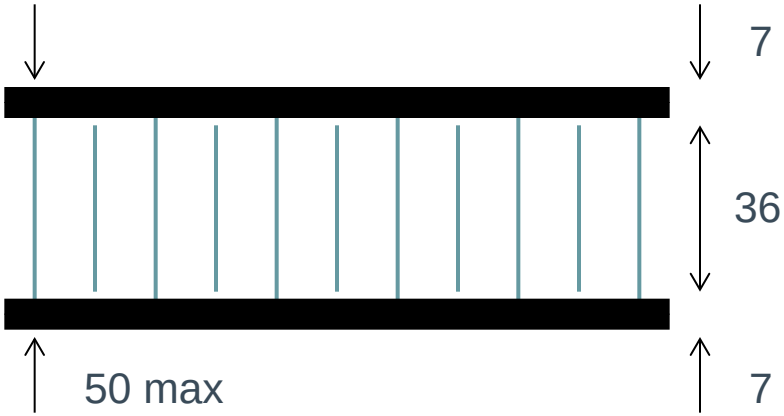
Load distribution from finite element analysis (FEA, Nastran).



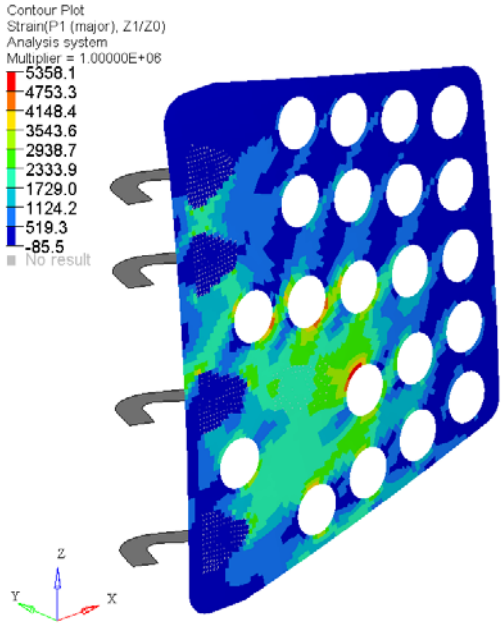
Structures – analysis, airbrake

Airbrake analysis examines static and dynamic response:

- Static calculation of:
  - Hinge and actuator bolted attachment forces
  - Face sheet running loads/stresses
  - Core transverse shear force.
- Dynamic assessment of natural frequency (>45Hz of fin).



dimensions in mm



Structures – analysis, wheel

The car *must* have four wheels.

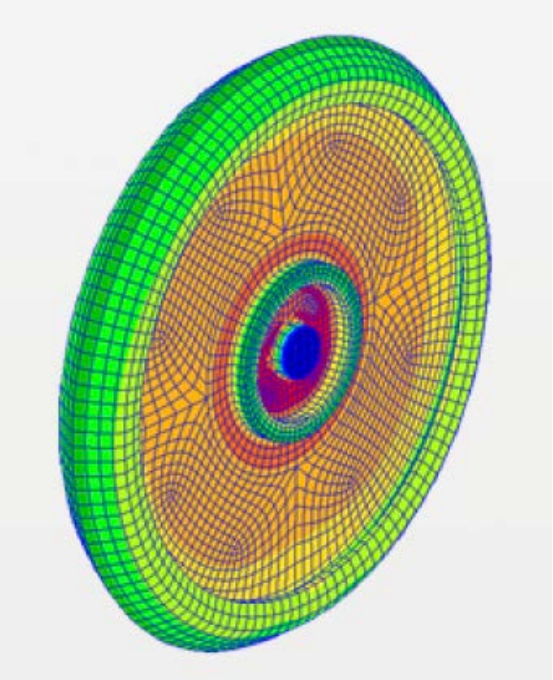
The wheels:

•are 36” diameter

•rotate at 9800rpm at 1050mph

•experience 50000’g’ at the rim

…hence are of solid Aluminum alloy.



Equivalent hoop stress 86ksi (600MPa).

Spin test at Rolls-Royce, Derby, Aug 26th 2014

Bloodhound in education

Key feature of the *Bloodhound* program:

- The education program, supplying ideas and resources across a range of school curricula
- Visiting STEM ambassadors explain the technology in schools
- Careers advice
- and...

website provides a wealth of resources for the teacher (and the engineer!)

http://www.bloodhoundssc.com/

Competition for the Record

	Bloodhound SSC	North American Eagle	Aussie Invader 5R	Jetblack
				
Origin	UK	North America	Australia	New Zealand
Engine	Turbofan, Hybrid Rocket	Turbojet, Afterburner	Bi-propellant Liquid Rocket	Turbojet, Hybrid Rocket
Power	135,000 HP	52,000 HP	200,000 HP	81,000 HP
Length	44 ft	56 ft	52 ft	43 ft
Weight	14,000 lb	13,000 lb	14,000 lb	16,000 lb
Speed	1000+ mph	800+ mph	1000+ mph	1000+ mph

Bloodhound SSC’s attempt