ME3B3 Mechanics of Solids – Micro Project

The Mechanics of ‘Ripple-Wall Slick’ Tyres in Drag Racing

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Background and Reason for Investigation:

Drag racing involves launching high-power vehicles from a standstill over a short distance. NHRA Top Fuel dragsters can reach **545.47 km/h (151.52 m/s) in just 3.64 seconds** [1], experiencing up to **4.24g** of acceleration thanks to an engine output of **11,000 HP (8.206 MW)** [2]. These extreme forces require specialised tyre mechanics.

Unlike road or F1 tyres, **ripple-wall slicks** are used, running at just **7.5 psi (51.7 kPa)** [3] to maximise grip. At launch, the tyres **squat**, increasing the ground-tyre contact patch and reducing torque spikes, thus preventing wheel slip. As speed increases, they **‘balloon’**, altering the drive ratio, enabling single-gear operation, and reduce in width, reducing friction at high speeds. This increase in tyre radius also means that each wheel covers more distance per revolution, allowing the car to reach top speeds.

This project investigates **radial expansion and forces on drag tyres** during extreme acceleration, analysing how these deformations impact performance.

Squatting at Rest

Ballooning at High Speed

Tire Specifications:

As per Goodyear’s 2025 tyre guide [4], Top Fuel dragsters use a special soft tyre compound called **‘D-2H’**. Below are some of the tyre specs. I could not find a definitive value for the elastic modulus of ripple-wall slicks online, but a research paper [5] carried out by the research division at Goodyear concluded that the modulus for tyre rubber ranges between 1.9-11.6 MPa. I will estimate the drag tyres to be around **E ≈ 3 MPa**.

Radius (m)	Section Width (m)	Tread Width (m)	Tyre Weight (kg)	Elastic Modulus (MPa)	Thickness (mm)	Density (kg/m^3) [6]
0.465	0.554	0.44	21.77	3	20	1100

Quantitative Analysis of Ballooning Phenomenon:

As we want to find the radial expansion of the tyres from rest to maximum velocity, we must calculate and derive some formulae.

Angular Velocity: $\omega = vr = (151.52)(0.465) = 70.46\, rads^{-1}$

Rotational Torque: $T = \frac{60P}{2\pi N} \rightarrow \frac{60(8.206\times10^{6})}{2\pi\left(\frac{60(70.46)}{2\pi}\right)} = 116.46\, kNm$

Deriving a Formula for the Total Radial Expansion:

Hooke’s Law: $\varepsilon_h = \frac{\sigma_h}{E} \rightarrow \frac{\Delta r}{r_0} = \frac{\sigma_h}{E}$

Incorporating Hoop Stress: $\sigma_h = \frac{Pr_0}{t} \rightarrow \frac{\Delta r}{r_0} = \frac{Pr_0}{Et}$

Radial Expansion due to Inflation Pressure: $\Delta r_p = \frac{Pr_0^2}{Et}$

Centrifugal Stress of Rotating Cylindrical Body: $\sigma_c = \rho\omega^2 r_0^2$

Hooke’s Law: $\frac{\Delta r}{r_0} = \frac{\rho\omega^2 r_0^2}{E}$

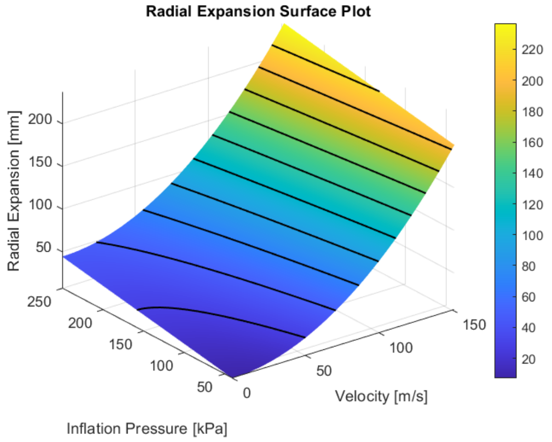
Radial Expansion due to Centrifugal Forces: $\Delta r_c = \frac{\rho\omega^2 r_0^3}{E}$

Total Radial Expansion: $\Delta r_{total} = \frac{Pr_0^2}{Et} + \frac{\rho\omega^2 r_0^3}{E}$

$$\Delta r_{total} = \frac{(51.7\times10^3)(0.465)^2}{(3\times10^6)(0.2)} + \frac{(1100)(70.46)^2(0.465)^3}{(3\times10^6)}$$

$$\boldsymbol{\Delta r_{total} = 0.202\, m}$$

Therefore, after accelerating from 0 to 545.47 km/h, the world record-breaking Top Fuel dragster saw its rear tyres increase in radius by approximately 20.2 cm!



Radial Expansion Surface Plot:

The above plot is a surface plot of a tyre’s radial expansion for different pressures. This was made using **MATLAB**. I varied the pressure using a matrix from 40 kPa (just below NHRA minimum tyre pressure [7]) and 250 kPa (standard road tyre pressure) and plotted it against a velocity matrix ranging from 0 to 150 m/s. **Around 50 kPa is the optimal pressure level** for Top Fuel tyres, as any significant amount above or below could see them explode. It would also hinder performance, as 50 kPa is recommended so that the contact patch is optimised for initial traction off the line.

[1] Fastest speed in an NHRA Drag Racing Top Fuel race (1,000 ft), [2] Engine Builder: Top Fuel and Funny Car Engines ,[3] We Break Down the Physics of Dragster Tyres [4] Goodyear Racing Tyres, [5] Young's Modulus of Rubber Compounds [6] Density of Tyre Rubber, [7] NHRA Top Fuel Minimum Tyre Pressure