Glossary of Terms

Agility

Ground vehicles are free roaming devices (with the exception of railed vehicles) in which the driver/rider seeks to influence path curvature and speed in order to follow an arbitrary course. The ease, speed and accuracy with which the operator can alter path curvature is agility. For motorcycles, the primary dictator of path curvature is roll angle, and therefore motorcycle agility discussions focus on roll behaviour; the handlebar is a roll acceleration demand. For finite track vehicles, path curvature arises from yaw rate; the handwheel is a yaw rate demand. Measures such as maximum speed through a given slalom crudely discern agility but not in a way that provides information on how to improve the design if more agility is desired.

Anti-aliasing

Anti-aliasing is analogue filtering applied to a signal before it is digitally sampled. Digital data should not be collected without an appropriate anti-aliasing filter. Aliasing is when something happens between subsequent samples that is simply 'missed' by the sampling process.

Consider Figure C.1; a 5 Hz process has been sampled at 4.762 Hz. Nyquist's theory predicts that spectral content is wrapped around according to multiples of half the sampling frequency. For the above example, the wrapping occurs at $5 - (2*4.762/2) = 0.238$ Hz. Once data have been allowed to alias, they cannot be 'unaliased'.

Anti-lift

Anti-lift is a geometric property of the suspension which means the reaction of traction-induced pitch moment is reacted entirely by tension in the mechanical suspension members (100% anti-lift), entirely by the roadspring(s) (0% anti-lift) or some combination of the two.

Anti-lift of less than 0% is described as 'pro-lift'. The concept is applicable only to a driven front wheel/axle and is thus generally inapplicable to motorcycles. Anti-lift is only applicable to a driven front wheel/axle. For a rear wheel/axle, the appropriate measure is anti-squat (q.v.)

For the behaviour of rear suspension geometry under braking this behaviour is sometimes referred to as 'anti-pitch'.

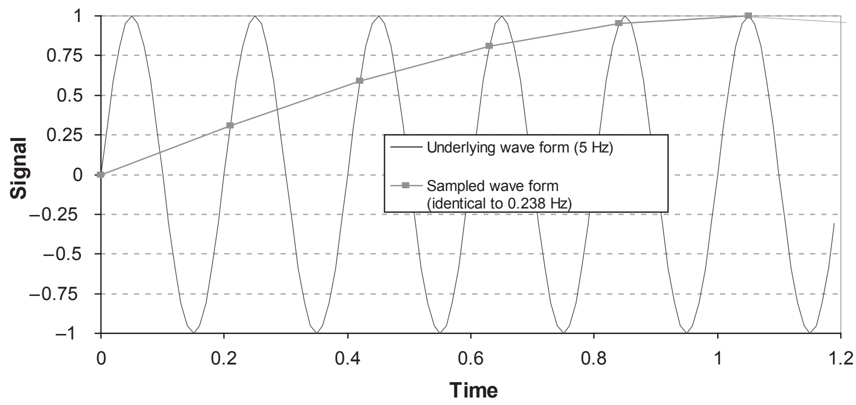

FIGURE C.1

Aliasing, which can only be prevented with an anti-aliasing filter.

Anti-pitch

Anti-pitch is a geometric property of the suspension which means the reaction of brake-induced pitch moment is reacted entirely by compression in the mechanical suspension members (100% anti-pitch), entirely by the roadspring(s) (0% anti-pitch) or some combination of the two. Anti-pitch of less than 0% is described as 'pro-pitch'.

Road motorcycles and comfort-oriented passenger cars have a typical inclination of the front suspension elements that provides pro-pitch behaviour. Rear suspension elements are often inclined to provide some anti-pitch under braking, but the effectiveness of this reduces with rear brake apportioning — little brake effort is apportioned to the rear of motorcycles braking hard and so it is generally ineffective at preventing pitch.

The term 'anti-dive' is not preferred since it has been used as a proprietary description for systems that modify front suspension damper calibration in order to resist brake-induced pitch in motorcycles.

For finite track vehicles, excessive anti-pitch geometry degrades refinement by forcing the wheel into any obstacles it encounters instead of allowing it to retreat from them. Brake-induced pitch behaviour is substantially modified by the use of inboard brakes.

Anti-roll

Anti-roll is a geometric property of the suspension that means the reaction of roll moment is reacted entirely by compression in the mechanical suspension members

(100% anti-roll), entirely by the suspension calibration (0% anti-roll) or some combination of the two. Less than 0% anti-roll is described as ‘pro-roll’. This concept is meaningless for motorcycles.

One effect of anti-roll geometry is to speed the transfer of load into the tyre for a given roll moment. By modifying this load transfer differentially from front to rear strong changes in character can be wrought, though they rarely result in fundamental changes in vehicle behaviour. (This is not to say they are of no import; race performance hinges on ‘character’ since it leads towards or away from a confident driver.)

Different anti-roll geometry from front to rear also acts to provide a yaw/roll coupling mechanism. For typical saloons that coupling is such that roll out of a turn produces a yaw moment out of the turn. This is given by more anti-roll at the rear than at the front axle. Vehicles with less anti-roll at the rear have a distinctive impression of sitting ‘down and out’ at the rear when driven aggressively; it rarely results in confidence.

Anti-squat

Anti-squat is a geometric property of the suspension where the traction-induced pitch moment is reacted entirely by compression in the mechanical suspension members (100% anti-squat), entirely by the roadspring(s) (0% anti-squat) or some combination of the two. Less than 0% anti-squat is described as ‘pro-squat’.

The calculation of anti-squat on a chain-driven motorcycle is nontrivial and must include chain tension reaction components in the free-body diagram for the swing-arm. Anti-squat is only applicable to a driven rear wheel/axle. For a front wheel/axle, the appropriate measure is anti-lift (q.v.).

Anti-squat is not a preferred term for the behaviour of front suspension geometry under braking; the preferred term for this behaviour is ‘anti-pitch’. The term ‘anti-dive’ is not preferred since it has been used as a proprietary description for systems that modify front suspension damper calibration in order to resist brake-induced pitch.

Articulated

An articulated vehicle is one in which two significant bodies are present and must pivot with respect to one another in order for the vehicle to follow a curved path. Motorcycles and tractor–trailer combinations are articulated.

Beta dot

See body slip rate.

Body slip angle

Body slip angle is the angle measured in the ground plane between the heading angle and the path of the vehicle. Heading may be thought of as what would be read by an onboard compass calibrated to the frame of reference in use. Path is the vector extending in the direction of travel at the current instant. Note that for all vehicles using pneumatic tyres, some body slip angle is inevitable to allow the rear tyres to generate a slip angle (q.v.) when travelling in a curved path.

Body slip rate

Body slip rate is the first time derivative of body slip angle (q.v.). Body slip rate is an angular velocity associated solely with creating or removing body slip angle. The total vehicle yaw rate (q.v.) is made up of the no-slip yaw rate (q.v.) — that part necessary for travelling in a curved path — plus the body slip rate. Body slip rate is zero in the steady state; the relationship between body slip rate and handwheel rate is crucial in modifying driver confidence. Unfortunately, for vehicles other than road cars on high friction surfaces it is difficult to discern experimentally since it relies on 'the small difference of two large numbers' and is thus prone to sensor noise.

Bump

Bump is a term used specifically to describe a motion of the suspension arrangement in which the wheel travels closer to the body. Its opposite is rebound (q.v.). Bump is also known as jounce.

Camber

Camber is the angle between a vertical line passing through the wheel centre and the lateral projection of that line onto the wheel plane (the projection being in the lateral direction). Strictly, it is absolute relative to the ground. A totally upright wheel has zero camber. A wheel lying flat on the ground has 90° camber.

Confusion can occur with finite track vehicles as to whether camber is measured with reference to the body coordinate system or a coordinate system on the ground. To ease this, the angle relative to ground can be referred to as the 'inclination angle' and that relative to the body as camber angle. A clear and unambiguous statement of the reference frame as often as is necessary is recommended to preclude ambiguity.

Castor

Castor is often referred to as rake (q.v.) for motorcycles. For finite track vehicles, it is the angle that the steering axis makes with the vertical when projected onto the plane of symmetry of the vehicle. For motorcycles, care needs to be taken that the angle of the fork legs, if fitted, may not be the same as the angle of the steering axis. In these conditions, ‘rake’ may be used for the fork legs and ‘castor’ for the steering axis.

Among the car community, there is frequent surprise at the notion that the steering axis need not pass through the wheel centre but may be offset from it when viewed the side; thus it is possible to have trail (q.v.) but no castor, or vice versa.

Some sugars are formulated to be thrown (‘cast’) from a device specially made for the purpose (a ‘caster’). They are not connected to steering systems in any way.

Centre of percussion

See inertial conjugate.

Centripetal force

Centripetal forces are the unbalanced forces that result in acceleration of a body towards the centre of its path curvature. Without them there is no curvature of path. A body travelling in a curved path is not in equilibrium.

Cepstrum

Cepstrum is a contrived word. It is an anagram of spectrum and is used to describe the Fourier transform of something already expressed in the frequency domain. The technique is used widely in sonar to identify patterns of frequency content such as that generated by rotating machinery. It is slowly creeping into industrial usage and may yet become a tool in the ground vehicle industry.

Coherence

Coherence is an unambiguously defined calculated quantity that describes the consistency of phase relationship between two spectral estimates. Whenever a cross-spectrum or transfer function is calculated, coherence should be calculated and used to assess the credibility of the results. Cross-spectra with a coherence of less than 0.9 should be regarded cautiously and those below about 0.8 should be rejected. Note that these judgements are made on a spectral-line-by-spectral-line basis and it is acceptable for data at 5Hz to be believable while that at 7 Hz is discarded.

Complex numbers

Complex numbers are numbers containing real and imaginary components. The imaginary component of a complex number is a real number multiplied by the square root of -1. 'Complex' thus has a specific meaning and should be avoided to represent 'complicated' or 'elaborate' in general discussion.

Eigenvalues (q.v.) calculated using complex numbers are 'complex eigenvalues'; those calculated without are simply 'real eigenvalues', as calculated in many finite element (q.v.) packages. Undamped eigenvalues for oscillatory systems as calculated in MBS systems are often purely imaginary.

Computational fluid dynamics

Computational fluid dynamics is a tool for addressing fluid dynamic problems. Closed form (classical) fluid dynamics solutions quickly become extremely cumbersome for any but the simplest problems and boundary layer complexity render closed form fluid dynamics forms inapplicable for any object of interest except perhaps for artillery shells and the like.

In a manner similar to finite element analysis (q.v.), computational fluid dynamics uses a large number of finite volumes, known as cells, for which closed form solutions are known. The equations are coupled by imposing conditions of compatibility between adjacent cells and solving the resulting problem numerically. The solution is a time domain integration across the whole problem region, which is extremely time-consuming for even quite simple bodies.

Contact patch (tyre)

The contact patch for a pneumatic tyre is that part of the tyre in contact with the ground.

Couple

A couple is one or more forces acting at a distance from some point of interest such that a moment is exerted at that point.

In rigorous usage it is distinct from a torque, which is sometimes referred to as a 'pure moment' to differentiate it from a couple. Pure moments are unusual; couples are much more common.

This distinction is of little importance in day-to-day use, and unless the distinction between couples and torques is germane to the discussion it is best left unmade; it usually adds more confusion than it avoids. 'Torque' is commonly used for both, and 'pure torque' as a distinction is acceptable.

Damper

A damper is a device that produces a force opposing a motion applied to it. Gyroscopic torques are not dampers although they are velocity-dependent, since they do not act to oppose a motion applied but instead act at 90° to that motion.

The term damper is frequently applied to mean a hydraulic device to the exclusion of other devices, but this is merely habit rather than preference. Dampers are not shock absorbers — they transmit shocks, not absorb them. The spring and damper assembly together could be described as a shock absorber. The term shock absorber, or 'shock' for short, is common in US usage and is often used to mean only the damper; a combined spring and damper unit is sometimes referred to as a 'coilover' in US usage. It is wise to check exactly which components are being discussed as often as necessary.

A dampener is something that adds moisture and has nothing to do with dynamics.

Dynamics

The Greek word 'δύναμις' (pronounced dunn-a-miss) means energy and is where we get our word dynamic from. In the sense frequently used today by mechanical engineers it is used to signify a time-varying exchange of energy between kinetic (motion), strain (stretching) and/or potential (height) states. Similar phenomena exist with electrical circuits and are crucial to the operation of radios and other elaborate equipment.

When this exchange occurs easily the system is said to be at resonance. It happens at characteristic frequencies (speeds of a repeated motion) for any structure. If an event happens at a speed substantially similar to or greater than the speed (frequency) of the slowest resonance, it will be dynamic or fast. If an event happens at less than that speed, it will be static or slow. For a full system, such as a motorcycle, the same is true. The correct understanding of the dynamic behaviour of vehicle systems at the design stage is vital to avoid costly mistakes being carried forward to the prototype stage or, worse, to production.

Dynamic absorber

A dynamic absorber is an additional spring-mass-damper system added to a mechanical system to take a single resonance and modify it by forming two resonances, each of which is more damped than the single resonance in the unmodified system. One of the two resonances is at a lower frequency than the original and the other is at a higher frequency.

Mass-damper systems can also be added to dissipate energy uniformly across a wide frequency range, and these devices are also sometimes referred to as 'dynamic absorbers'. Finally, discrete lumped masses can be firmly attached to change resonant frequencies in order to decouple an excitation from a structural resonance. Such a device is frequently and confusingly referred to as a 'mass damper' although it would be less ambiguous to call it an inertial attenuator.

Eigensolution, eigenvalues, eigenvectors

There is a clear mathematical description of characteristic solutions ('eigen' is German for 'characteristic') of matrix problems, but it is unhelpful for this glossary.

Eigensolutions, which consist of eigenvalues and eigenvectors, are quite simply free vibration solutions — that is to say resonances, or 'natural solutions' for the system described by the matrix problem. If the system is heavily damped (more than around 5% damping ratio) then complex numbers are necessary for useful eigensolutions of the system. If it is lightly damped then only real numbers are necessary.

Eigensolutions are also sometimes referred to as 'modal solutions', 'normal modes' and a variety of other titles. Thus a 'real normal modes' solution is one that solves the eigenvalue problem for a lightly damped system, using only real numbers. Note that it is a property of modes of vibration calculated in this manner, that they are normal (orthogonal) to one another; they produce a dot product of zero if the vectors are multiplied together. The concept of orthogonality requires at least two items for it to be meaningful.

Expected and unexpected response

Expected response is not the subjective vagary it might be supposed. Expected response is defined clearly for dynamics usage as the product of the system inputs and the idealised characteristics of the system. For example, in yaw for a finite track vehicle the expected response is a yaw rate, the value of which is the forward speed multiplied by the steer angle and divided by the wheelbase. This might also be called 'idealised yaw rate'. 'Idealised' does not imply 'ideal' in the sense of most optimum.

The reason for wishing to capture the expected response is to compare it with the actual response. The difference between actual and expected is then logically termed 'unexpected response' and is important in quantifying operator interpretation of the vehicle. One vehicle might display a yaw response that differs from another by only a few percent; for example, a comparison of the unexpected components of response might show that one has double the unexpected response of the other and explain the strong preference of operators for one over the other even though the objective overall response is very similar.

If the terms 'expected' and 'unexpected' cause consternation then the control theory terms 'reference' (demanded) and 'actual' could be substituted.

Finite element method

Simple engineering structures can be represented using a closed-form equation derived using differential calculus. The beam equation is the most widely used of these forms, being familiar to most engineers. These might be thought of as infinitesimal (infinitely small) element solutions, being derived by considering an infinitesimal slice then summing (integrating) the results.

The derivation of closed form solutions for more complex structures subject to complex loading patterns rapidly becomes cumbersome and impractical. The finite element method uses small but not infinitesimal chunks of the structure, each of which has a closed form solution, and assembles them imposing conditions of force and displacement continuity at the boundaries between elements. The resulting set of simultaneous equations is converted to matrix form and is well suited to being solved using a digital computer.

The finite element method was invented in principle during the latter stages of World War II and immediately thereafter, but did not achieve widespread use until the Apollo programme in the 1960s in America. In the last 30 years it has become more and more popular, with FE tools now available for use with home computers.

Forced response

Forced response is the response of a system under some external excitation. Excitation is usually time-varying; if it is not then the problem is a static one.

If the input excitation has been established for some time then the behaviour of the system will have achieved 'steady state' (q.v.); the response will be stationary (q.v.) in character. Such solutions can be calculated using the 'harmonic forced response' method. A transfer function is calculated based on the free vibration (natural solution) response of the system then multiplied with the frequency spectrum of the input excitation to provide a response spectrum. Refinement (q.v.) problems are frequently addressed using the harmonic forced response method.

If the input excitation has not been established for some time, then a solution method is required that can capture the developing phase relationships in the system. This is a 'transient forced response'. There is typically a computational resource penalty of an order of magnitude when switching to transient solution methods from harmonic ones.

Gain

Gain is often used when discussing control systems to describe the relationship between output(s) and input(s). A system with a higher gain produces larger outputs for a given input than a system with a lower gain. Gains may or may not be linear and often vary with input frequency.

In vehicle dynamics, quantities like yaw rate and lateral acceleration are regarded as the output when compared to handwheel angle as an input. For a motorcycle, roll acceleration is the output and steer torque is the input.

Occasionally gain is used when talking about the rate of increase of a quantity, for example when discussing the development of roll angle during a transient manoeuvre. Such confusing usage is unhelpful when clearer terms like "increase" and "rate" are available.

Gyroscope, gyroscopic torques

Much mystique surrounds gyroscopes and gyroscopic torques. Gyroscopes do not produce forces, only torques (moments). Gyroscopic torques are a logical consequence of Newton's third law in its correct and full form. Sometimes expressed succinctly as 'applied force is equal to rate of change of momentum', if a full 6x6 formulation is pursued then differentiating the product of the inertia tensor and velocity vector yields some off-diagonal terms if the inertia tensor varies with time, as it does with a rotating body that is not spherical.

Handwheel

Handwheel is the preferred term for what is popularly called the steering wheel. The reason for this distinction is that a typical car has three steering wheels — two are road wheels and the other is the handwheel. Using handwheel avoids ambiguity although it may seem a little cumbersome.

Harmonic

Harmonic in dynamic terms means 'consisting of one or more sine waves'.

When the phrase 'assume harmonic solutions' is used, it means 'assume the solution consists of one or more sine waves'. There is no implication of fixed frequency relationships; the term harmonic is sometimes confused in careless usage with 'harmonies' as used in music.

Heave

Heave is one of three motions performed by the whole vehicle on its suspension, referred to collectively as 'primary ride'. It is a motion whereby the whole vehicle rises and falls evenly, with no rotation about any axis. The other two ride motions are pitch and roll. For motorcycles the roll motion is not a primary ride motion but the fundamental degree of freedom for the vehicle. Heave is also known as bounce, or jounce.

In reality, ride motions are never pure heave or pitch but always some combination of the two. This fact is a frequent source of confusion between development staff and analysis staff; the two groups use the terms differently. The problem is even more acute when including roll, with confusion around the notion of the 'roll centre' as a motion centre for the vehicle.

Inertial conjugate (centre of percussion)

Inertial conjugate is the preferred term for the location at which no translation occurs when a free body with finite mass and inertia properties is loaded in a direction that does not pass through its centre of gravity. No translation occurs at this point during load application, whether or not the load is percussive (an impact). This phenomenon gives rise to the behaviour of 'rigid' bats in some sports, particularly baseball and the like, that is described as the 'sweet spot'. This is not to be confused with the use of the same term for strung rackets.

The term 'centre of percussion' is not preferred to describe this location since it implies a percussive loading must be present for the concept to be useful.

Jounce

Jounce is another term for heave. It is of US origin.

Kinematics

Kinematics is the study of motion. In a mechanism it is the study of the motion of the individual motions of the components and how they relate to and constrain each other.

Modes, modal analysis

Modes is shorthand for 'modes of vibration'. See 'eigensolution' for a description. 'Modal' is an adjective meaning 'of or relating to a mode or modes'. Modal analysis is thus a fairly loose term; its preferred use is as part of the expression, Experimental Modal Analysis, or better still Modal Test, in which experimental methods are used to discern the modes of vibration of a structure. Analysis to predictively calculate modal behaviour is distinguished by the expression 'modal solution' (solution being a general word for the submission, retrieval and interpretation of a set of results to a problem using a digital computer).

Multibody system analysis, multibody codes

Mechanical systems can be viewed as a connection of separate items, or bodies, connected by various means. Such a system, comprised of multiple bodies, can be analysed by the application of Newtonian or Lagrangian methods to formulate the equations of motion, which may then be interrogated in a variety of ways — integrated through time, solved for an eigensolution and so on. This is multibody system analysis.

A group of software packages, or codes as they are informally referred to, have emerged that greatly ease the task of formulating and solving the equations of motion. The best known is called MSC ADAMS — Automated Dynamic Analysis of Mechanical Systems — developed by MSC Software.

Until recently, an implicit assumption in this type of analysis has been that the elements comprising the system are rigid, but this limitation is being removed by the elegant integration of multibody methods with structural dynamics methods.

No-slip yaw rate

No-slip yaw rate is the yaw rate required to support a vehicle travelling in a curved path, allowing it to change heading in order to have the correct orientation when it leaves the corner.

If the vehicle did not yaw when travelling in, say, a 90° corner then it would be travelling sideways upon exiting the corner. If it is to be travelling forwards (in a vehicle-centred sense — i.e. as noted by the operator) when it leaves the corner then it must have rotated in plan during the corner.

Consideration of basic physics leads to the observation that no-slip yaw rate is centripetal acceleration divided by forward velocity.

Non-holonomic constraints

> *'Non-holonomic constraints involve nonintegrable relationships between velocities. In vehicle dynamics they arise typically if wheels are assumed to roll without slip in problems of more than one dimension. Suppose a car is parked in an open, flat, high-friction area and radial line marks are appended to the tyre sidewalls and to the points on the ground nearest to them. The car is then driven slowly, without tyre slip, round the area and eventually returned to the precise location where it started. Although the car body can be repositioned precisely the tyre marks will not, in general, align now'.*

Sharp, R.S. Multibody Dynamics Applications in Vehicle Engineering (1998).

NVH

See Refinement.

Objective

Objective is unfortunately ambiguous. In one sense (as a noun) it is similar to 'target' but that is not its preferred usage. The preferred usage is in contrast with 'subjective' (q.v.) and is as an adjective. It refers to measurements or conclusions that are independent of the person who observes. The term arises from basic English sentence construction which is 'subject-verb-object'. If A observes B then B is the object of A's observation; B is always B whether A or C observes.

Objectivity is essential to dynamic activities; without it work cannot be credible, reproducible or professional. These three are prerequisite for any scientific activity.

Operating Shape

When harmonically (q.v.) excited, a system will respond with a characteristic motion that varies over time and for lightly damped systems may often be represented as a scaled sine wave for each point in the system with a fixed phase relationship.

Examining the system at the maxima of these individual sine waves gives a characteristic shape at which the system operates. When operating at resonance, the operating shape strongly resembles the mode shape or eigenvector (q.v.) associated with that resonance.

For heavily damped systems the scaling is usually complex (q.v.), meaning that operating shapes cannot readily be assimilated without animation.

Oversteer, understeer

Oversteer is strictly the condition in which the slip angle of the rear tyres exceeds that of the fronts. Understeer is strictly the reverse.

Before debating this matter, a review of Segel and Milliken's papers from 1956 are in order, where all this was laid down as fact with test work and mathematical development. The definitions arrived at in there are applicable in the linear region only. The persistence of their usage for limit behaviour is an extension beyond their validity. Sometimes, drivers may refer to oversteer and mean a yaw overshoot after turn-in, which is somewhat confusingly a consequence of an understeering car. Equally, a car that has genuine oversteer behaviour will have non-oscillatory roots to its characteristic equation, resulting in excessive yaw damping that manifests itself as a reluctance to turn in and is reported as transient understeer.

Some modern cars have steady state oversteer behaviour on low grip surfaces since it dulls response and makes the vehicle manageable, even though it guarantees the need for driver correction.

Preferred alternative forms of reference are such subjective terms as ‘push on’ or ‘loose rear’ (that is loose, not lose) or more technical descriptions, such as ‘real roots for the characteristic equation’, ‘rear slip angle exceeds front’ and so on.

The importance of both oversteer and understeer as steady state phenomena in road vehicles in the linear region is greatly exaggerated. Its prime effect in the steady state is to encourage the driver to adjust the handwheel slightly, since it results in a path error due to the difference between demanded [idealised, expected (q.v.)] and no-slip yaw rates (q.v.). In normal road driving this is completely trivial; fitting a ‘faster’ steering rack will mask the perception of path error related to understeer completely.

For transient handling, the development of body slip angle (q.v.) is of much more importance; the yaw rate associated with changes in body slip angle is acutely sensed by the driver and is used to give warning of an impending spin even though it is only a small fraction of the total yaw rate. If the vehicle manages its body slip rate poorly, then it can give the impression of an impending spin even if no such event was likely. Even at low lateral accelerations, body slip rate is a strong modifier on perceived transient performance.

Path error

Path error is a preferred term for steady state understeer. When the vehicle ‘runs wide’ from the driver’s intended path, the normal driver response is to add more steer angle. If the lateral acceleration is high and the path error is large, then more steer angle may not help reduce path error. This situation is reported by many drivers as ‘pushing on’ and is common limit handling behaviour for safe road vehicles.

Path error is strictly the difference between idealised [demanded, expected (q.v.)] yaw rate and no-slip yaw rate (q.v.). It is a numerical quantity suitable for discernment from logged data or mathematical models.

Pitch

Pitch is one of three motions performed by the whole vehicle on its suspension, referred to collectively as ‘primary ride’. It is a motion whereby the front of the vehicle rises and falls in opposition to the rear of vehicle, rotating about the lateral axis of the vehicle. The other two ride motions are heave and roll. For powered two wheelers the roll motion is not a primary ride motion but the fundamental degree of freedom for the vehicle.

Sometimes compound heave (q.v.) and pitch motions are referred to as ‘front end heave’ or ‘rear end heave’ in a verbal effort to describe the operating shape (q.v.).

Predictive methods

Predictive methods is an umbrella term for all forms of mathematical modelling, from statistical to explicit, from numerical to algebraic.

'The only relevant test of the validity of a hypothesis is comparison of prediction with experience' (Milton Friedman)

PTW

PTW is an acronym for 'powered two wheeler' – a generic term encompassing mopeds, scooters, motorcycles, enclosed motorcycles, feet firsts (FFs) and any other thing which has two wheels and is self-powered.

Rake

Rake is the angle between the steering axis and the vertical for an upright motorcycle. Typical values for rake vary from 23° for a sports machine and over 30° for a cruiser. Rake is also known as castor (q.v.), and is occasionally quoted as an angle from the ground plane. Some designs of motorcycles have a different angle for the steering axis and the telescopic fork legs; in this case rake is sometimes used for the fork leg angle and castor reserved for the steering stem angle.

Rate

Rate means, clearly and unambiguously, the first time derivative. It is shorthand for 'rate of change with time'. Using rate for derivatives other than time is not preferred. In particular, using rate as in 'spring rate' is undesirable; 'stiffness' is preferred in this instance, though the authors make this error frequently.

Rebound

Rebound is a term used specifically to describe a motion of the suspension arrangement in which the wheel travels away from the body. Its opposite is bump (q.v.).

Refinement

Refinement is a general term that refers to the ability of a vehicle to isolate its operator and other occupants from external disturbances and from disturbances generated by the vehicle itself – for example engine vibration.

Refinement is frequently referred to as 'NVH'. This stands for 'Noise, Vibration and Harshness'. The distinction between the three phenomena is not well defined. It is suggested that noise refers to audible phenomena from 30 Hz upward, vibration to dynamic phenomena below about 10 Hz and harshness to tactile sensations of vibration of intermediate frequency, for example, steering column shake at idle.

Segment

'Segment' is industry shorthand for 'market segment' — the term used to define the objectives for the vehicle in terms of who will buy how many copies of it.

Shock absorber

See Damper.

Slip, slip angle (of tyres)

Slip is perhaps the poorest word possible to describe the behaviour of a tyre under lateral loading. A rolling tyre will not support a lateral load due to the repeated relaxation of the sidewalls just behind the contact patch. This action causes the tyre to 'walk' sideways under an applied lateral load. Combined with the forward motion, this results in an angle between the wheel plane and the direction of motion. That angle is dubbed the 'slip angle'. The presence of a slip angle does not imply sliding friction at the contact patch, despite the linguistic link between slip and slide. This is a frequent source of confusion for newcomers to the field.

To further add confusion, the behaviour of a tyre under a tractive or braking torque is also referred to as slip, and is often quantified in percentage. A free-rolling wheel is at zero slip, a completely locked wheel is at 100% brake slip. 100% tractive slip is when the wheel is spinning twice as fast as the free-rolling wheel. The presence of tractive/braking slip does not imply sliding friction at the contact patch, though this is the case at high slip percentages (greater than 20%), as it is at high slip angles (greater than about 6°).

Stability

Stability means the response to a disturbance is bounded (non-infinite). In practical terms for a motorcycle this would mean it would not fall over if nudged. This is clearly not the case when the machine is at rest but is generally true of the motorcycle/rider combination at all speeds above zero. For running vehicles, the notion of stability is generally associated with the control of body slip angle (q.v.) and

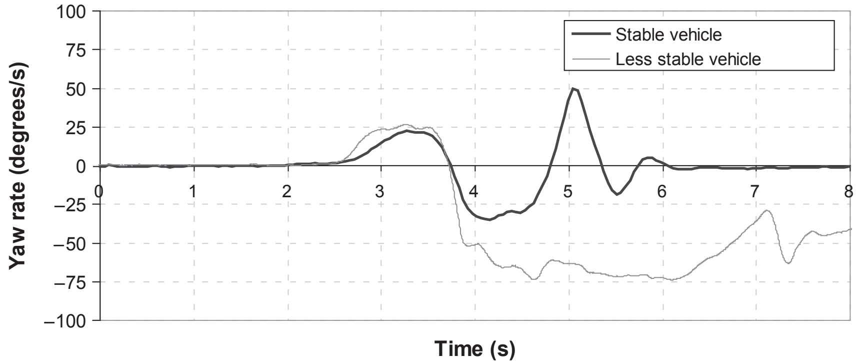

FIGURE C.2

Time Domain Comparison of Stable and Less Stable Vehicle during 120 kph Entry Chicane Manoeuvre.

hence implicitly the yaw rate behaviour of the vehicle. In practice a response that is simply 'finite' is insufficient to guarantee stability in any useful sense; vehicles are not simply 'stable' or 'instable' but have degrees of stability that are often related to the nature of the nonlinearity of the system. For example, the front wheel wobble (q.v.) problem on a motorcycle is unstable on-centre but has a 'bounded instability' in the sense that the increasingly nonlinear behaviour of the tyres dissipates more and more energy as the amplitude of the cycle rises. This has the effect of 'containing' the instability in the system within bounded limits.

Figure C.2 shows a comparison between a vehicle that has a passively stable response and another with a less stable response during a chicane manoeuvre. Both vehicles have comparable mass, wheelbase, inertia properties and tyre fitments. The manoeuvre is completed off-throttle and it can be seen that the less stable vehicle produces a very aggressive yaw acceleration at the steer reversal (3.8 s) and a high yaw rate persists for some time, resulting in a half spin of the vehicle.

It can be seen for a well-controlled manoeuvre like this one, performed under identical conditions with the same driver, it would be easy to formulate some measure of stability based on area under the yaw rate curve. To compare vehicles on an absolute basis requires a well-controlled test that is tester-, venue- and weather-independent — a more difficult task but addressed in part by the ISO manoeuvres.

Stationary

In dynamics, stationary does not mean immobile. It is a property of a time-domain signal and is such that lengthening the observation period does not alter the fundamental characteristics (mean, RMS, Standard Deviation, etc.) of the signal.

Steady state

In general, steady state refers to the condition where phase relationships are fixed and no longer vary with time.

In the sense used in vehicle dynamics work, it is that definition applied to a vehicle cornering. The phase relationship between all motions of the vehicle is fixed; there is neither yaw nor roll acceleration that is anything other than established and harmonic. In the simplest sense the vehicle is travelling steadily on a curved path. Note that steady state does not imply equilibrium.

Steering offset

Steering offset is a fairly general term that has specific meanings when considering the steering system of a finite track vehicle. It is the lateral distance between the steer axis and the wheel plane. It can be seen that if the steer axis is inclined when viewed from the front of the vehicle (as is generally the case) then this offset has different values at different heights above ground.

Wherever it is measured, positive steering offset is when the wheel plane is outboard of the steer axis. Negative steering offset is the reverse.

Steering offset is of interest at ground level since it determines steering system loads (and hence handwheel torque) under differential longitudinal loads. Excessive ground level offset promotes nervousness under braking and sensitivity to ABS operation. However, it also assists the driver in retaining control under split mu braking conditions, with or without ABS. Negative ground level offset makes the handwheel and vehicle insensitive to ABS operation.

The steering offset at wheel centre height, usually called 'hub level offset' dominates the sensitivity of the vehicle to tractive effort imbalance — usually called 'torque steer'. It also strongly colours the amount of vibration passed through to the driver from the road surface under normal driving — so-called 'texture feel'. With a driven axle, steering offset is normally the outcome of drive shaft plunge calculations and not an independent design variable in its own right.

Subjective

Subjective is in contrast with 'objective' (q.v.) and is an adjective. It refers to measurements or conclusions that are dependent on the person who observes.

It would be unfair to suggest that subjectivity has no place, but excessive reliance on unreproducible observations is unhelpful, unproductive and unprofessional.

Symbolic codes (multibody system analysis)

> *'Conceptually, the simplest approach to solving…(a multi-body system problem) is to give the whole set of differential and algebraic equations to a powerful and appropriate solver… Simulations tend to be painfully slow…' 'Symbolic preparation of the problem for numerical solution implies that the symbol manipulations, which are performed only once ahead of numerical processing, can be devoted to making the (later repeated) numerical operations minimal. It also implies independence of the symbolic equation building and the numerical solution'.*
>
> Sharp, R.S. Multibody Dynamics Applications in Vehicle Engineering (1998).
> Simpack is one of several symbolic codes on the market at the time of writing.

Traction, tractive

Traction for ground vehicles is the process of deploying power via a torque at the road wheels in order to provide a forward force on the vehicle. Such force is sometimes referred to as 'tractive effort'. Multiplying that force by the vehicle velocity gives 'tractive power'.

Trail

Trail is the distance between the point at which the steering axis intercepts the ground plane and the front wheel contact patch centre. Positive trail implies the steering axis intercepts the ground ahead of the front wheel contact patch. Trail can be measured at two different points; the geometric centre of the contact patch and the centre of lateral load of the contact patch. The difference between the two measurements is often referred to as 'pneumatic trail'. The measurement to the geometric centre of the contact patch is then 'mechanical'.

With finite track vehicles, trail is an important contributor to the self-aligning behaviour of the steering system and handwheel efforts.

With motorcycles, negative trail machines existed into the 1920s but the destabilising effects with speed rendered them impractical for high-speed use. Negative trail occasionally appears on mountain bicycles today and does not guarantee instability of the machine/rider system. At low speeds, high roll angles and significant steer angles, trail is substantially modified by the wheel geometry.

Transient (cornering)

In general, transient refers to the condition where phase relationships are not fixed and are varying with time. In the sense used in this work, it is that definition applied to a vehicle cornering. Transiently, the phase relationship between all motions of the vehicle is developing and changing. Rates of change are generally decaying with time and the transient motion becomes the steady state motion if sufficient time is allowed. For the transient aspects of the motion to decay completely, something around 3 s is required for cars and motorcycles. This is rarely achieved in practice and so reality consists of a connected series of transient events.

Understeer

See Oversteer.

See Expected Response.

Vehicle dynamics

For the purpose of this work, a vehicle is defined as a wheeled device capable of propelling itself over the ground. Dynamics, from the Greek 'dunamis (δύναμις)' meaning power or the capability to achieve something, is the study of time-varying phenomena. Most dynamic phenomena involve the shuffling or transforming of energy between one item in a system and another. The phrase 'vehicle dynamics' is generally used to refer to phenomena of interest to the rider or driver of the vehicle in guiding its path — roll, turn-in, and so on. It includes consideration of elements such as tyres and suspension dampers, and is very much a system level activity.

Vehicle programme

'Vehicle programme' is industry shorthand for 'vehicle design, development and sign-off programme'. It is that defined activity that takes as input a desire to have a vehicle in a certain market segment and produces as output a fully mature design, ready to be mass produced. The start of vehicle programmes is shrouded in obfuscation in order that each manufacturer can claim their vehicle programmes are shorter than others; the end of the vehicle programme is frequently referred to as 'job 1' or 'launch'.

Weave

Weave is one of the lowest fundamental modes of vibration of a motorcycle. It is a combination of roll, yaw and lateral motion that results in the machine following a sinuous path. Modern road machines rarely display weave behaviour poorly damped enough to hinder the rider's control of the machine but even current machines can display a low enough level of weave damping to diminish the rider's confidence, particularly when laden. The highest performance machines typically employ an aluminium beam frame concept and have excellent weave damping, to the point where weave mode cannot readily be discerned with a typical 'rider rock' manoeuvre (a hands-off hip flick) but must instead be found using a swept sine handlebar input.

Wheelbase

Wheelbase is the distance between the front and rear wheel centres of a wheeled vehicle.

Wheel hop

A description of the system resonance that consists of the unsprung mass (wheel, tyre, brake components, hub, bearings and some proportion of suspension members, springs and dampers) as the dominant kinetic energy storage and the tyre as the dominant strain energy storage, with the tyre providing the dominant energy dissipation route. Typical frequencies are usually around 12 Hz on a finite track vehicle, 15 Hz on a road motorcycle.

Wheel trajectory map

A collective name for the characteristics that describe the orientation and location of the wheel plane in relation to the vehicle body. The characteristics are all defined with respect to bump (q.v.) motion. In a finite track vehicle, the wheel trajectory map includes bump steer, bump camber, bump recession and bump track change. The interaction of each of these characteristics with the vehicle is subtle and complicated. For motorcycles it is generally only bump recession, also known as anti-pitch or anti-squat, that is of interest.

Wobble

Wobble is a faintly comical term used to describe a distinctly serious trait of motorcycle behaviour. Originally referred to as 'speedmans's wobble' this was shortened to just wobble by frequent usage. It describes the mode of vibration of a motorcycle in which the steered mass is in motion more-or-less independently of the non-steered mass and rider. It is typically around 8 Hz and generally well damped enough that it does not present a problem. However, when ill-damped it can present a terrifying experience whereby the amplitude of the motion set-off by some small disturbance grows until it is only restrained by the steered mass colliding with some part of the motorcycle at each extreme. It is also referred to as flutter, shimmy or headshake.

Yaw, yaw rate

Yaw is simply rotation when viewed in plan view. Yaw rate is the first time derivative and is often referred to as yaw velocity. Yaw is measured in degrees or radians and yaw rate in degrees/second or radians/second.