| Sawtooth Reference | year | title | T/C/E | n | Geom | resolution | L/N | model | result |
|---|---|---|---|---|---|---|---|---|---|
| Eriksson and Wahlberg, Phys. Plasmas, **9** 1606 | 2002 | Effect of combined triangularity and ellipticity on the stability limit of the ideal internal kink mode in a tokamak | T | **1** | T | | L | Ideal MHD | The effect of combined positive ellipticity and triangularity is stabilizing. This extends the work of Wahlberg, Phys. Plasmas 5, 1387 (1998) |
| Huysmans, Hender, Hawkes, Litaudon, Submitted to Phys. Rev. Lett | 2001 | MHD Stability of Advanced Tokamak Scenarios with Reversed Central Current: an explanation of the Current Hole | C | 0 | C | 0/0 and 0/1 only | QL | finite beta three-field reduced MHD | simple model with only 2-modes qualitatively agrees with data |
| Hawkes, N.C. et al, PRL **87** 115001 | 2001 | Observation of Zero Current Density in the Core of JET Discharges with Lower Hybrid Heating and Current Drive | E | 0 | C | - | | | Current ramping and LHCD produce a region of zero current density, implying the existence of a physical mechanism preventing it from becoming negative. |
| Reimerdes, et al, Plasma Phys. Control. Fusion **42** 629 | 2000 | Effect of triangular and elongated plasma shape on the sawtooth stability | E | | | | | | Experiments were done on TCV to determine the dependence of the sawtooth period and amplitude on the shape of the poloidal plasma cross section. Relation to ideal MHD theory. |
| Sugiyama and Park, Phys. Plasmas, **7** 4644 | 2000 | A nonlinear two-fluid model for toroidal plasma | C | 1 | C | $S=3x10^4$ | N | two-fluid MHD | Ion diamagnetic drift stabilizes 1/1 mode, explained due to flow pattern |
| Nishimura, Callen, and Hegna, Phys. Plasma **6** 4685 | 1999 | Onset of high-n ballooning modes during tokamak sawtooth crashes | C | 1 | T | 500/151 | | finite beta, three-field reduced MHD | at high $\beta$, 1/1 mode induces unstable high-n ballooning modes which induce stochasticity and lead to incomplete reconnection |
| Hastie RJ, Astrophysics and Space Science **256** 177 | 1998 | Sawtooth Instability in Tokamak Plasmas | | | | - | | | not in PPPL library |
| Wahlberg, Phys. Of Plasmas, **5** 1387 | 1998 | Analytical stability condition for the ideal m=n=1 kink mode in a toroidal plasma with elliptic cross section | T | | | | | | Ellipticity has a strong destabilizing effect on the kink mode. Effects of triangularity not considered. |

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| Aydemir, A, PRL **78** 4406 | 1997 | Nonlinear m=1 Mode and Fast Reconnection in Collisional Plasmas | C | 1 C | dynamic | N | low-β reduced two-field MHD | exponential nonlinear growth (but slower than linear) |
| Lutjens and Luciani, Phys. Plasmas 4 4192 | 1997 | Stability thresholds for ballooning modes driven by high β internal kinks | C | 1 T | ?? | QL | full MHD | The nonlinear destabilization described in [Park,1995] is looked at for a more general class of parameters. Nonlinear destabilization occurs if the initial equilibria is close to marginal stability for the n>3 modes. |
| Wang and Bhattachargee, Phys.Plasmas **4** 1173 | 1997 | Comment on "Collisionless m=1 reconnection in tokamaks" | T | 1 | - | | | Rodgers and Zakharov 1996 paper citing explosive growth due to generalized Ohm's law agrees with 1993 and 1995 W&B papers and with Aydemir. |
| Rogers and Zakharov, Phys. Plasmas **4** 1175 | 1997 | Response to "Comment on 'Collisionless m=1 reconnection in tokamaks' " | T | 1 | - | | | disagree with equation used by W&B linking the poloidal flow speed along the reconnection layer to the plasma pressure |
| Chang, Park, Fredrickson, et al. PRL **77** 3553 | 1996 | Off-Axis Sawteeth and double-tearing reconnection in reversed magnetic shear plasmas in TFTR | E/C | 1 C | S=105-6 | N | resistive MHD | 2-types of off-axis sawtooth when qmin crosses 2 due to double-tearing: off-axis and on-axis. Simulation of off-axis. Time-scales similar to q=1 sawtooth. |
| Nagayama, McGuire, Bitter, et al, Phys. Plasmas **3** 1647 | 1996 | Tomography of full sawtooth crashes on TFTR | E | | | | | Reconnection is 3-D, localized on bad curvature side. Experimental results do not agree with 2D models. Q-profile does not change during crash |
| Nagayama, G.Taylor, M.Yamada, et al | 1996 | ECE Image reconstruction of partial sawtooth crashes in Ohmic Plasmas | E | | - | | | Partial sawteeth sometimes observed when qa < 3. Caused by (2,2) or (3,3) mode. The (1,1) mode normally occurs after the partial crash. |
| Porcelli, et al, Plasma Phys. Control. Fusion **38** 2163 | 1996 | Model for the sawtooth period and amplitude | T | | | | | A sawtooth model for ITER is presented. Crash is triggered by m=1 mode driven by MHD, high energy particles, and thermal trapped particles. Kadomtsev or incomplete reconnection. |

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| Rodgers and Zakharov, Phys. Plas. **3** 2411 | 1996 | Collisionless m=1 reconnection in tokamaks | T/C | 1 Slab | 335/261 | N | two-field, two-fluid, reduced | fast nonlinear growth in early stage of nonlinear reconnection |
| Haas and Thyagaraja, Plasma Phys. Controlled Fusion 37 415 | 1995 | Turbulence and the nonlinear dynamics of sawteeth in tokamaks | T | | | | simple model equations | Turbulence relaxation model keeps q<1 and fixed. |
| Park, Fredrickson, Janos, et al, Phys. Rev. Lett **75** 1763 | 1995 | High-β Disruption in Tokamaks | C | T | | N | resistive MHD, but not entirely self-consistent | ideal (1,1) saturated state causes toroidally localized high-n ballooning mode produces local pressure bulge which develops into disruption |
| Rogers and Zakharov, Phys. Plasmas **2** 3420 | 1995 | Nonlinear ω* stabilization of the m=1 mode in tokamaks | T/C | 1 Slab | | | 3-field, two fluid reduced | m=1 mode with q(0) < 1 can be linearly stabilized by w*. Regimes that are linearly unstable can be non-linearly stable due to w* effects, with non-singular current layer. |
| Soltwisch and Koslowski, Plasma Phys. Controlled Fusion **37** 667 | 1995 | Sawtooth modulation of the poloidal field in TEXTOR under ohmic heating conditions | E | | | | | In reproducible ohmic plasmas, q0 = 0.73 and dq0 = 0.06 during the ramp. Poloidal field perturbation localized at the large major radius side of the q=1 surface. May agree with [Park,1991] |
| Wang and Bhattachargee, Phys Plasmas **2** 171 | 1995 | Nonlinear dynamics of the m=1 kink-tearing instability in a modified MHD model | T | C | | | 3-field, two fluid reduced | Electron pressure gradients can cause near-explosive growth in the nonlinear regime of a m=1 island, followed by a rapid decay phase. Model could explain fast crash times, sudden onset, and incomplete reconnection. |
| Biskamp and Drake, Phys. Rev. Lett **73** 971 | 1994 | Dynamics of the Sawtooth Collapse in Tokamak plasmas | C | 1 C | | N | 2-fluid reduced MHD with electron inertia and viscosity | fast reconnection driven by electron inertia occurs in two steps. A fast Kadomtsev-type reconnection is followed by a rapid reformation of a q0 < 1 configuration, driven by the strong flows. |
| Gimblett and Hastie | 1994 | Calculation of the post-crash state and 1 1/2D simulation of sawtooth cycles | C | 1 C | | N | 1 1/2D model of sawtooth | resistive interchange model keeps q(0) < 1 during the sawtooth cycle |
| Levinton, Zakharov, Batha, et al, Phys Rev. Lett **72** 2895 | 1994 | Stabilization and onset of sawteeth in TFTR | E | 1 | | | | In TFTR q(0) < 1 , normally, but sawteeth are not always present. Small change during crash implying full reconnection does not occur. Theory predicts ideally unstable. Presence or absence of sawteeth agrees well with ω* criteria in [Zakharov,1993] |

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| Rice and Hooper, Nucl Fusion **34** 1 | 1994 | Poloidal field measurements during sawteeth and disruptions on MTX | E | | | | | Polarimeter measurements on MTX show $q_0$ ~ 0.7-0.85 during sawteeth, with $\Delta q_0$ ~ 0.01 during the sawtooth |
| Yamada, Levinton, Pomphrey, Phys. Plasma **1** 3269 | 1994 | Investigation of magnetic reconnection during a sawtooth crash in a high-temperature tokamak plasma | E | | | | | Electron temperature flattens in ~ 200 ms, but q-profile hardly changes. q0 = 0.7, Dq0 < 0.1, observations agree with Baty, et al (1993) |
| Biskamp and Drake, Proceedings of the 15th IAEA Conference, Seville, IAEA-CN-60/D-7, Vol 3, p261 | 1994 | Dynamics of the Sawtooth Collapse in Tokamak plasmas | C | | | | | Same basic story as in Biskamp and Drake, PRL 73 971 (1994) |
| Zakharov, Levinton, Batha, et al, Proceedings of the 15th IAEA, Seville, IAEA-CN-60/D-19, Vol 3, p 407 | 1994 | Onset and stabilization of sawtooth oscillations in tokamaks | E/T | | | | | for finite amplitude perturbations, the influence of the ideal mode disappears and the criteria of $\omega$* -stabilization of the collisionless m=1 reconnection mode determines the sawtooth-free operational space in tokamaks |
| Baty, Luciani, and Bussac, Phys. Fluids B **5** 1213 | 1993 | Field line stochasticity during the m=1 reconnection | C | 1 T | $S=10^5$, 200x10x11 | N | resistive MHD | Toroidal modulation of the m=1 resistive mode drives sidebands, and different magnetic island chains with m up to 10 overlap, leading to an annular stochastic region. This can expel the electron temperature in less than 100 microsec, removing the drive for the instability, and the central core could be pushed back without change in the value of q(0). |
| Levinton, Batha, Yamada, Zarnstorff Phys Fluids B 5 2554 | 1993 | q-profile measurements in TFTR | | | | | | q0 = 0.7, Dq0 < 0.1 during crash. q=1 radius changes less than 1 cm. Some discharges with same q0 < 1 have 1,1 activity but no sawteeth |
| Ottaviani and Porcelli, Phys. Rev. Lett. **71**, 3802 | 1993 | Nonlinear collisionless magnetic reconnection | C | 1 slab | 1026/64 | N | two-field model with electron inertia | quasi-explosive time behavior in early nonlinear stage with formation of current density sublayer narrower than the skin depth. |
| Waelbroeck, Phys. Rev. Lett. **70** 3259 | 1993 | Onset of the sawtooth crash | T | 1 C | | | low-$\beta$ reduced two-field MHD | tearing vs kink-tearing: gives theory basis why sawteeth in toroidal geometry fundamentally different than in cylindrical |

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| Wang and Bhattachargee, Phys. Rev. Lett. **70**, 1627 | 1993 | Nonlinear dynamics of the m=1 instability and fast sawtooth collapse in high-temperature plasmas | T | C | | N | four-field model | analytical model explaining many features of [Aydemir,1992] Explosive growth followed by rapid decay are shown to follow from Hall term. Electron inertia not important |
| Wolf, O'Rourke, Edwards et al, Nucl Fusion **33** 663 | 1993 | Comparison of poloidal field measurements on JET | E | | | | | Measurements of q0 on JET by both Faraday and MSE agree and show q0 ~ 0.7-0.85 throughout the sawtooth cycle: partial reconnection does occur |
| Wroblewski, Phys Rev. Lett, **71** 859 | 1993 | Evidence of the Complete Magnetic Reconnection during a sawtooth collapse in a tokamak | E | | | | | In DIII, $q_0$ is measured by MSE to be near 1.0, and $\Delta q_0$ = 0.06. [Wroblewski,1991] may be wrong |
| Zakharov,Rodgers, Migliuolo, Phys. Fl. B **5**, 2498 | 1993 | The theory of the early nonlinear stage of m=1 reconnection in tokamaks | T | 1 C | | L/ N | three-field model | Hall term dominates in Ohm's law. Gives fast experimental crash times. Density and temperature gradients are stabilizing. (criteria given) Nonlinear cancellation of the w* stabilization is possible triggering mechanism. |
| Aydemir, A, Phys.Fluids B **4** 3469 (1992) | 1992 | Nonlinear studies of m=1 modes in high-temperature plasmas | C | 1 C | 600/256 | N | four-field reduced model with hyperresistivity | accelerated nonlinear growth with 2-fluid physics. Y-point becomes X-point. Electron inertia probably not essential. Complete reconnection. |
| Coppi and Detragiache, Phys. Lett A **168** 59 | 1992 | Magnetic topology transitions in collisionless plasmas | T | | | | | It is shown that collisionless processes can lead to fast sawtooth crash times, but only if the growth rate exceeds the drift frequencies. |
| Kolesnichenko, Yakovenko, et al, Phys Rev Lett **68** 3881 | 1992 | Sawtooth Oscillations with the central safety factor, q0, below unity | T | 1 C | | | simple ideal MHD conservation laws | cartoons showing it may be possible to have reconnection and keep q0 < 1 |
| Lutjens, et al, Nuclear Fusion 32 1625 | 1992 | Ideal MHD stability of internal kinks in circular and shaped tokamaks | C | 1 T | | L | ideal MHD | The internal kink is significantly destabilized by ellipticity. |
| Nagayama and Edwards, Rev. Sci. Instr **63** 4757 | 1992 | Rotational soft x-ray tomography of noncircular tokamak plasmas | E | | | | | Pictures of soft X-ray signals in slow sawtooth crash in JET. Identical in structure to TFTR (Nagayama,1991) |
| Rice, Rev. Sci. Instrum **63** 5002 | 1992 | Fifteen chord FIR polarimetry system on MTX | E | | | | | on MTX $q_0$ remains at .78 +- 0.08 during sawtooth oscillations. |

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| Soltwisch H Plasma Phys. Control. Fusion **34** 1669 (Review Article) | 1992 | Current Density Measurements in Tokamak Devices | E | | | | | Confusing results of $q_0$=1 reported on ATC, ASDEX, TCA. Low values of $q_0$ < 0.8 reported on PBX-M, DIII, TEXTOR, JET, PDX, TOKAPOLE II. |
| Zakharov,Rodgers, and Coppi, Phys Fluids B **4** , 3285 | 1992 | Two-fluid MHD description of the internal kink mode | T | | | L | | The scale length for electron and ions decouple. For the ions, the scale length is $\rho_S = C_S/\Omega_{ci}$. 2-fluid equations agree well with kinetic studies. |
| Aydemir, Phys. Fluids B **3**, 3025 | 1991 | Linear studies of m=1 modes in high-temperature plasmas with a four-field model | C | 1 C | | L | four-field reduced model with finite electron inertia | The four-field model reproduces dispersion relations obtained with more complete kinetic treatments. |
| Berk, Mahajan, Zhang, Phys. Fluids B 3 351 | 1991 | m=1 kink mode for layer widths comparable to the ion Larmor radius | T | | | | FLR MHD | strong dependence of stability result on the local shear at the q=1 surface |
| Biskamp, Phys. Fluids B **3**, 3353 (1991) | 1991 | Algebraic nonlinear growth of the resistive kink instability | T | 1 C | | N | reduced two-field resistive MHD | geometrical modifications to slab Sweet-Parker theory give increased resistive growth rates. |
| Drake and Kleva, Phys. Rev. Lett 66 1458 | 1991 | Collisionless reconnection and the Sawtooth Crash | C | 1 slab | 1000/132 | N | isothermal compressible MHD with electron inertia and anomalous current diffusion | Electron inertia by itself cannot produce fast reconnection times. However, the addition of a anomalous current diffusion term, due to instability of the current layer, can lead to fast reconnection. |
| Lichtenberg, Itoh, et al, Nucl. Fusion 32, 495 | 1991 | The role of stochasticity in sawtooth oscillations | T | | | | | Stochastization of field lines , resulting from the interaction of the 1,1 helical mode with other harmonics plays an important role in the sawtooth. It leads to enhanced values of electron and ion viscosity and thermal conduction. |
| Nagayama, McGuire, Bitter, et al, Phys. Rev. Lett **67** 3527 | 1991 | Analysis of Sawtooth Oscillations using simultaneous measurement of electron cyclotron emission imaging and X-Ray tomography on TFTR | E | | | | MHD + stochasticity enhanced transport coefficients | Analysis of temperature data indicate a full thermal reconnection, but no magnetic measurements were used and thus nothing can be said about q0 or flux surfaces. |

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| O.Rourke J Plasma Phys. Control. Fusion 33 289 | 1991 | The change in the safety factor at a sawtooth collapse | E | | | | | in JET, $q_0$ = 0.7 while the change during the sawtooth is $\Delta q_0$ < .05. Hence, complete reconnection of the poloidal flux does not take place. |
| Park, Monticello, Fredrickson, and McGuire Phys. Fluids B **3** 507 | 1991 | Finite pressure effects on sawtooth oscillations | C | 1 T | S=3x105,200 radial | N | resistive MHD | finite p0 or shaping cause a toroidal bulge at the large R side, causing an annular stochastic region outside q=1. However, computes full Kadomtsev reconnection |
| Porcelli, Plasma Phys Controlled Fusion, **33**,1601 | 1991 | Fast Particle Stabilization | T | | | | | The stabilization of plasma macroscopic instabilities by high energy particles is shown to be a consequence of the conservation of the third adiabatic invariant. |
| Porcelli, Phys. Rev. Lett. 66 425 | 1991 | Collisionless m=1 tearing mode | T | 1 slab | | L | fluid electrons with inertia | In the collisionless regime, magnetic reconnection occurs because of finite electron inertia, and the ion gyroradius replaces the skin depth as the width of the mode boundary layer. Fast growth rates ~ 50-100ms are found for JET parameters |
| Wesson, Edwards, Granetz, Nucl. Fus **31** 111 | 1991 | Spontaneous m=1 instability in the JET sawtooth collapse | E | | | | | Model in [Jahns,1978] or [Aydemir,1989] does not describe JET sawteeth in either the time scale, flow pattern, or time-development of the growth rate. Sudden appearance of the fast growth rate cannot be understood by standard linear theory. |
| Wroblewski and Lao, Phys Fluids B 3 2877 | 1991 | Determination of the safety factor in sawtoothing discharges in DIII-D | E | | | | | Here it is reported that $q_0$ < 1 during sawtooth discharges, and $\Delta q_0$ ~ .05. However, this is somewhat retracted in a later article by the same author[1993] |
| Aydemir, Phys. Fluids B **2** 2135 | 1990 | MHD modes driven by anomalous electron viscosity and their role in fast sawtooth crashes | C | 1 T | S=108, 765/48 | N | resistive MHD + hyperresistivity | anomalous electron viscosity can lead to faster growth rates for the crash phase, in approximate agreement with experiment. However, still computes full reconnection |
| Coppi, et al, Phys Fluids B 2 927 | 1990 | Global modes and high-energy particles in ignited plasmas | T | | | | | Fusion-produced alpha particles with trapped orbits can stabilize m=1 internal modes in an ignited plasma. There are stable and unstable regimes. |
| Janicki, C., et al., Nucl. Fusion 30 950 | 1990 | Tomographic analysis of compound sawteeth on the TDV | E | | | | | High resolution tomographic analysis of soft X-ray emission show details of compound sawtooth, which indicates partial reconnection. Time scales too fast for Kadomtsev. |

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| Park, W. and Monticello, D. Nucl. Fus **30** 2413 (1990) | 1990 | Sawtooth Oscillations in Tokamaks | C | 1 T | S=106 | N | resistive MHD | neoclassical resistivity, complete reconnection, $\Delta q_0$=0.2, $t_{ST} \sim 9R^2T^{3/2}$/Zeff |
| Rogister,et al, Phys. Fluids B 2 953 | 1990 | The mechanism of sawtooth precursors and sawtooth relaxations | T | 1 | | L | resistive MHD | It is argued that delta-prime for the m=1 depends sensitively on the shear and current density at the q=1 surface. This sensitivity of growth rate to plasma parameters could account for the sawtooth crash. |
| Wesson, Nucl Fusion **30** 2545 | 1990 | Sawtooth reconnection | T | 1 C | | | resistive MHD + electron inertia | The electron inertia term in ohm's law must be kept in the reconnection layer. Using this in a modified Sweet-Parker theory shows it will increase the predicted crash time and layer width in JET by 10. |
| Aydemir, Wiley, and Ross Phys. Fluids B **1** 774 | 1989 | Toroidal studies of sawtooth oscillations in tokamaks | C | 1 T | S=105-6, 100x4x11 | N | resistive MHD, eta depends on p, constant kappa. | full reconnection, transition from stable to unstable state with growing n=1 mode half-way through the cycle. Unstable mode grows for 50% of sawtooth period. Shows development and healing of stochastic regions. Note later paper by Wesson[1991] casts doubt on this work. |
| Campbell, et al in Plasma Phys and CNFR, Nice, 1988, IAEA Vienna Vol I, p377 | 1989 | Sawtooth activity and current density profiles in JET | E | | | | | Direct measurement of the q-profile show q(0) is below unity in sawtoothing plasmas and may be 0.6-0.8 during the stable periods. |
| Levinton, et al Phys Rev. Lett **63** 2060 | 1989 | Magnetic field pitch-angle measurements in PBX-M using MSE | E | | | | | Measurements on PBX-M show q(0)=0.86 in ohmic and q(0)=0.77 in NBI plasmas. These are supported by 2 other measurements. In addition, q® is flat out to about a/3 and well blow unity. |
| Moyer, Goetz, et al, Phys. Fluids B **1** 2139 | 1989 | q measurements during sawtooth oscillations in a low q tokamak | E | | | | | q(0) in TOKAPOLE-II is 0.7 during a sawtooth oscillation [note it is not clear if they correctly took plasma shape into account] |
| Pegorado, Porcelli, et al, IAEA, Niece, 1988, Vol 2, p243, IAEA-CN-50/D-IV-6 | 1989 | Theory of sawtooth stabilization in the presence of energetic ions | T | | | | | Energetic particles affect the stability of internal kink modes and can lead to plasma regimes where both sawtooth and fishbone oscillations are suppressed. |

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|---|---|---|---|---|---|---|---|---|
| Pegoraro, Procelli, et al, Phys. Fluids B 1 364 | 1989 | Internal kink modes in the ion-kinetic regime | T | 1 | slab | L | collisional electrons, collisionlesss ions | When the width of the singular layer is determined by the mean ion gyroradius, the growth rates are larger than the corresponding ones from fluid theory, and diamagnetic stabilization is weaker. |
| Sato, et al, Phys. Rev. Lett **63** 528 | 1989 | Supersaturation and nonlinear crash of tokamak sawtooth oscillations | C | 1 T | S=3x104 in center ??x??x?? | N | resistive MHD | high beta (10%) plasma undergoes kink instability when q(0)=1. Then, second axis forms and q(0) falls to 0.8. Finally, fast ideal time scale reconnection occurs bring q(0) to 1.0. Claim that compressibility is important |
| Snider, Phys. Fluids B **1** 404 | 1989 | Modification of sawteeth by second harmonic EC heating | E | | | | | A factor of 6 increase in sawtooth period is observed when ECE heating is localized at the q=1 surface. |
| Vlad and Bondeson, Nucl. Fusion **29** 1139 | 1989 | Numerical simulations of sawteeth in tokamaks | C | 1 C | S = 107, 200x4 | N | low-β reduced two-field MHD + temperature equ. | "Self-consistent" calculation leads to very flat central q profiles with q(0)=1. This q profiles allows a resistive mode to turn on quickly and with a high growth rate. Collapse scales weaker than $S^{1/2}$, more like $S^{1/3}$. Results depend strongly on ratio of viscosity to conductivity. Δq(0) decreases with S. |
| Waelbroeck, Phys. Fluids B **1** 2372 (1989) | 1989 | Current sheets and nonlinear growth of the m=1 kink-tearing mode | T | 1 C | | N | low-β reduced two-field MHD | shows theoretical basis for current-sheet singularity and rapid reconnection |
| Westerhof, E. et al., Nucl Fusion **29** 1056 | 1989 | Observations of sawtooth postcursor oscillations in JET and their bearing on the nature of the sawtooth collapse | E | | | | | Radial Te profile measured with high time resolution with ECE. Shows a m=1 island cold region and displaced hot plasma core. Conclusion that partial and full collapses are related, but with different nonlinear evolution. |
| Aydemir, Phys. Rev Lett **59** 649 | 1988 | Mechanism for Rapid Sawtooth Crashes in Tokamaks | C | 1 T | ??x??x?? | N | resistive MHD | Ideal instabilities exist for low shear systems even when q(0) > 1. Very sensitive to q' or a off-axis minimum near 1. Speculated to lead to fast crash times. |
| Campbell, et al, Phys. Rev. Lett **60** 2148 | 1988 | Stabilization of sawteeth with additional heating in the JET tokamak | **E** | | | | | The sawtooth instability is suppressed for periods up to 1.6 s when NBI is added. Not clear if it is due to q(0) > 1, or other stabilization of the 1/1 mode. |

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| Charlton, Carreras, Holmes, et al, Phys. Fluids, 31 347 | 1988 | Tokamak m=1 MHD calculations in toroidal geometry using a full set of nonlinear resistive MHD equations | C | 1 T | S=105, ??x??x?? | N | resistive MHD with "incompressible" or "pressure convection" equation of state | nonlinear results are sketchy, but depend on S, aspect ratio, and equation of state. Incomplete reconnection can be found for "pressure convection", A=4. However, there is a warning that this is valid only for high beta. Transition from resistive kink to resistive tearing at small A and large S. |
| Coppi, Hastie, Migliuolo, et al | 1988 | Suppression of Internal Plasma Oscillations by Trapped High Energy Nuclei | T | | | | kinetic MHD | sawteeth are shown to be stabilized by magnetically trapped energetic nuclei |
| Goedheer and Westerhof Nucl. Fusion **28** 565 | 1988 | Sawteeth, Transport and electron cyclotron heating in T-10 | T | 1 1D | model | - | 1D transport modeling | It is shown that a simple "turbulent model" for sawtooth evolution fits the data much better than the "reconnection model" [Jahns,1978] |
| **H. Soltwisch, Rev. Sci. Instrum 59 1599** | **1988** | **Measurement of current-density changes during sawtooth activity in a tokamak by FIR** | **E** | | | | | **The axial current density is measured to have an average of q(0)=0.77 with a modulation amplitude of about 8%. This precludes the classical Kadomtsev model.** |
| Wroblewski, Huang, and Moos, Phys. Rev. Lett. **61** 1724 | 1988 | Determination of the poloidal magnetic field profiles in a tokamak by polarization spectroscopy … | **E** | | | | | The on axis safety factor on TEXT is found to be close to 1.0. There is a decoupling of the current and temperature profiles and a flat current density profile in the center of the discharge. Note this contradicts [West,1987] |
| Hastie, Hender, Carreras, et al, Phys. Fluids 30 1756 | 1987 | Stability of ideal and resistive internal kink modes in toroidal geometry | C | 1 T | | L | ideal and resistive MHD | Results are presented on the stability of ideal and resistive m=1 internal modes near marginal stability. |
| Kleva, et al, Phys. Fluids **30** 2119 (1987) | 1987 | The fast crash of the central temperature during sawteeth in tokamaks. | C | 1 C | 40x400 | N | two-field reduced MHD | It is postulated that q(r) first falls below one at finite radius $r_s$, while q(0) stays near 1. This leads to "ideal" timescale modes and fast crashes. |
| McGuire,K. et al, in Plasma Physics and Controlled Nuclear Fusion research 1986 (Proc. 11th Int. Conf. Kyoto,) Vol. 1, IAEA, 421 | 1987 | Coherent and turbulent fluctuations in TFTR | E | | | | | three types of sawtooth activity in TFTR: simple, small, and compound. Not explained by Kadomtsev model. |

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| Park, Monticello, and Chu, Phys Fluids **30**, 285 | 1987 | Sawtooth stabilization through island pressure enhancement | C | 1 C | N | helical compressible resistive MHD equations | The m=1 mode can saturate when the pressure inside the magnetic island is heated and becomes greater than that of the original core plasma |
| Izzo R, Monticello DA; Stodiek W, Park W. | 1987 | Stochasticity and the m=1 mode in tokamaks | C | 1 | | | |
| Soltwisch, Stodiek, et al, IAEA Kyoto Vol 1 p263 | 1987 | Current density profiles in the TEXTOR tokamak | E | | | | The central safety factor in TEXTOR is measured by Faraday Rotation to be as low as 2/3. |
| Wesson et al, in Plasma Physics and Controlled Nuclear Fusion research 1986 (Proc. 11th Int. Conf. Kyoto,) Vol. 2, IAEA, 3 | 1987 | Sawtooth Oscillations | C | 1 C | N | cylindrical, incompressible | Sawtooth oscillations may be quasi-interchange modes, but this requires very flat q profiles with q(0)>1. Does not explain rapid onset of collapse. |
| West, et al, Phys Rev Lett **58** 2758 | 1987 | Measurement of the rotational transform at the axis of a tokamak | E | | | | q(0) in TEXT is measured to be 0.7-0.8. Note this is later contradicted in [Wroblewski,1988] |
| Biskamp, Phys. Fluids **29**, 1520 | 1987 | Magnetic reconnection via current sheets | C | 1 C | N | two-field reduced MHD | The current sheet at the singular surface can itself become unstable to tearing modes. |
| Campbell D. J. et al Nucl. Fusion **26** 1085 | 1986 | Sawtooth activity in ohmically heated JET plasmas | E | | | | JET sawtooth do not agree with Kadomtsev model: No precursor for collapse of compound sawteeth. Crash time too fast |
| Denton, Drake, Kleva, Boyd, Phys. Rev. Lett. **56** 2477 | 1986 | Skin currents and compound sawteeth in tokamaks | C | 1 C | | two-field reduced MHD with temperature equ. | if the thermal conductivity is small near the axis and increases outward, q(0) stays near 1 but falls below 1 at a finite radius. This leads to both normal and compound sawteeth. |
| Edwards, Campbell, et al, Phys. Rev. Lett **57** 210 | 1986 | Rapid collapse of a plasma sawtooth oscillation in the JET tokamak | E | | | | The central hot region in JET collapses in about 100 microsec, with a rapid transition to a configuration with poloidal symmetry. Does not agree with Kadomtsev model, but may agree with Wesson,1986 |
| Hazeltine, Meiss, Morrison Phys Fluids **29** 1633 | 1986 | Analytic theory of the nonlinear m=1 tearing mode | T | 1 C | | two-field reduced MHD | The m=1 tearing mode is shown to continue to grow exponentially well into the nonlinear regime, in contrast to the slow growth of the m>1 modes. |
| Wesson, J. Pl. Phys. Control. Fus. **28** 243 | 1986 | Sawtooth oscillations | T | 1 C | | ideal MHD | It is suggested that if q is flat in the center, just above 1, and falls below 1 at a finite radius, a fast sawtooth crash can occur. |

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| Park, Monticello,White., Phys. Fluids **27** 137 | 1985 | Reconnection rates of magnetic fields including the effects of viscosity | C | 1 C | S=107, 200x15 | N | 2D 2-field reduced MHD with scalar resistivity and viscosity | numerical reconnection rate agrees with modified Sweet-Parker when viscosity is large enough. When viscosity is small, reconnection is intermittent or unstable to higher m modes. |
| Dubois, Pecqet, and Reverdin, Nucl. Fusion **23** 147 | 1984 | Internal Disruptions in the TFR Tokamak: A phenomenological Analysis | E | | | | | Detailed analysis of high-speed X-ray data of sawteeth show it does not agree with the total reconnection [Kadomtsev] model. They propose a model where a "turbulent" region grows up around the island at the q=1 surface. |
| Lichtenberg, Nuclear Fusion **24** 1277 | 1984 | Stochasticity as the mechanism for the disruptive phase of the m=1 tokamak oscillations | T | | | | | The disruptive phase of the sawtooth can be caused by the onset of stochasticity caused by the (1,1) mode interacting with the (1,0) toroidal effects. |
| Manickam, Nuclear Fusion, 24 595 | 1984 | Stability of n=1 internal modes in tokamaks | C | 1 T | | L | ideal MHD | The internal kink can be stable in a torus at sufficiently low pressure. Ellipticity is destabilizing, and triangularity is stabilizing. |
| Osborne, Dexter, and Prager, Phys. Rev. Lett **49** 734 | 1984 | Discharges with Safety Factor q(0) < 1 in a Noncircular Tokamak | E | | | | | TOKAPOLE II discharges have q(0) =0.6 as directly measured with magnetic probes. Sawtooth oscillations are present, but q(0) remain stationary and below 1 during the sawtooth. |
| Parail, Pereverzev, Sov. J. Plasma Phys. **6** 14 | 1983 | Internal disruption in a tokamak | T | 1 | | | | Variation of the Kadomtsev model with the q-profile non-monotonic. Claims to solve the "trigger" problem which Kadomtsev does not. |
| Basu and Coppi, Phys. Fluids **24** 465 | 1982 | Theory of m=1 modes in collisionless plasmas. | T | 1 C | | | | Finite electron mass can destabilize otherwise stable ideal m=1 modes. But a temperature gradient can stabilize. Reconnection layers of the order of the ion gyroradius. |
| Park, Monticello, White, Jardin Nucl. Fus. **20** 1181 | 1981 | Nonlinear saturation of the internal kink mode | C | 1 C | 350/30 | | Ideal MHD | Current singularity forms in ideal MHD |
| McGuire, Robinson, Nucl. Fus. **19** 505 | 1980 | Sawtooth oscillations in a small tokamak | E | | | | | Sawteeth are present in TOSCA with a repetition time of 0.12ms. Comparison with other tokamaks indicate the sawtooth period scales like a reconnection time. |

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| Jahns, Soler, Waddell, et al, Nucl Fus. **18** 609 | 1979 | Internal Disruptions in Tokamaks | T | | | | | A model is put forward for the internal disruption and compared with ORMAC data. q(0) drops below 1, tearing mode=> magnetic reconnection=>q(0) > 1 |
| Ara, Basu, Coppi, et al, Ann. Phys **112** 443 | 1978 | Magnetic reconnection and m=1 oscillations in a current carrying plasma | T | 1 C | | L | | gives general theory for linear kink in a cylinder, including ideal, resistive, FLR, electron drift wave, ion-ion collisions. Refers to Coppi, Phys Rev Lett 12 417 (1964) for gyroviscous cancellation. Cannot have layer width < ion gyroradius. |
| Zakharov, Sov. J. Plasma Phys. **4** 503 | 1978 | Internal kink mode in a tokamak | T | 1 T | | | | Supports the calculation given in [ Bussac, 1975] |
| Dnestrovskij, et al, Sov. J. Plasma Phys **3** 9 | 1977 | Numerical simulations of internal-mode relaxation oscillations in a tokamak | C | 1 C | 1D | | transport equations | simple transport equation implementation of the Kadomtsev reconnection model |
| Coppi, et al, Sov. J. Plasma Phys **2** 533 | 1976 | Resistive Internal Kink Modes | T | C | | L | resistive MHD | Considers the 1D theory of internal kink modes with resistive corrections which are the same order. |
| Sykes and Wesson, Phys. Rev. Lett **37**, 140 | 1976 | Relaxation Instability in Tokamaks | C | 1 C | 14x14x10 | | resistive MHD, high beta | Supports the Kadomtsev model, but is in a high-beta cylinder |
| Waddell, Rosenbluth et al, Nucl. Fusion **16**, 528 | 1976 | Nonlinear growth of the m=1 Tearing Mode | C | 1 C | $S=5x10^4$ | N | reduced two-field resistive MHD | The m=1 tearing mode grows fast enough in the nonlinear regime to explain the crash times of the present experimental data |
| Kadomtsev, B.B. Sov. J. Plasma Phys. **1** 389 (1975) | 1976 | Disruptive instability in tokamaks | T | 1 C | | | | Presents basic m=1 reconnection model. Predicts that q(0) < 1 before event, and q(0) = 1 after reconnection |
| Rosenbluth, Dagazian, Rutherford, Phys Fluids **16**, 1894 | 1976 | Nonlinear properties of the internal m=1 kink instability in the cylindrical tokamak | T | C | | N | | Shows that the ideal m=1 instability saturates at a small amplitude with a singular current sheet. |
| Bussac, Phys Rev. Lett. **35** 1638 | 1975 | Internal Kink Modes in Toroidal Plasmas with Circular Cross Sections | T | 1 | | | Ideal MHD | The ideal Internal Kink Mode can be stable in toroidal geometry for circular cross section plasmas if the pressure gradient is sufficiently low. This is contrary to the known result in cylindrical geometry. |
| Rutherford, Phys. Fluids 16 1903 | 1975 | Nonlinear growth of the tearing mode | T | | | | | Classic nonlinear tearing mode reference. However, does not apply to the m=1 mode. |

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| Von Goeler, Stodiek, and Sauthof, Phys. Rev. Lett. **33** 1201 | 1973 | Studies of Internal disruptions and m=1 oscillations in tokamak discharges with soft-X-ray techniques | E | | | | first to use the term "sawtooth oscillation" |
| Shafranov, Sov. Phys. Tech Phys. **15**, 175 | 1970 | Hydromagnetic stability of a current-carrying pinch in a strong longitudinal | T | C | L | Ideal MHD | Gives basic cylindrical stability theory, and the condition q(a) > 1 |

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