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Objective

To establish Phase State of Control we require stoichiometric measures ensure balance, autonomy and visibility but we must also beware of the false assumption that even when efficacy of control has been achieved in accordance with **Table 1** that this new reality as expressed by F is immune to entropy.

Balance	Autonomy Threshold	Visibility Ratio
$\sum B_{Solution} - \sum C_{Expression} = 0$	$\sum C_{Soltiuon} \rightarrow 0$	$\sum F_{Solution} \geq 2$

Table 1: Stoichiometric Efficacy of Control

Control exists within the boundaries of a system's thermodynamic environment. The post-catalytic state (where C→0 and F=5) is a high-energy configuration. Entropy is an omnipresent pressure attempting to collapse the system into a noisy, disordered state. In this examination as before, we will look to stoichiometry to provide the active counterbalance to entropy.

In data science, best practice has it that an analytic solution is applied such that "the tub fills at the rate that it drains." This principle provides us with a mass-balance approach to entropy. If we treat Fidelity (F) as water in the tub, then the drain is the inevitable decay of physical and informational accuracy that results from entropy. In this examination, we endeavor to determine how much C must be applied to redirect a system that has decayed so that it can maintain F=5, much like a satellite fires small jets to keep its orbit in trim.

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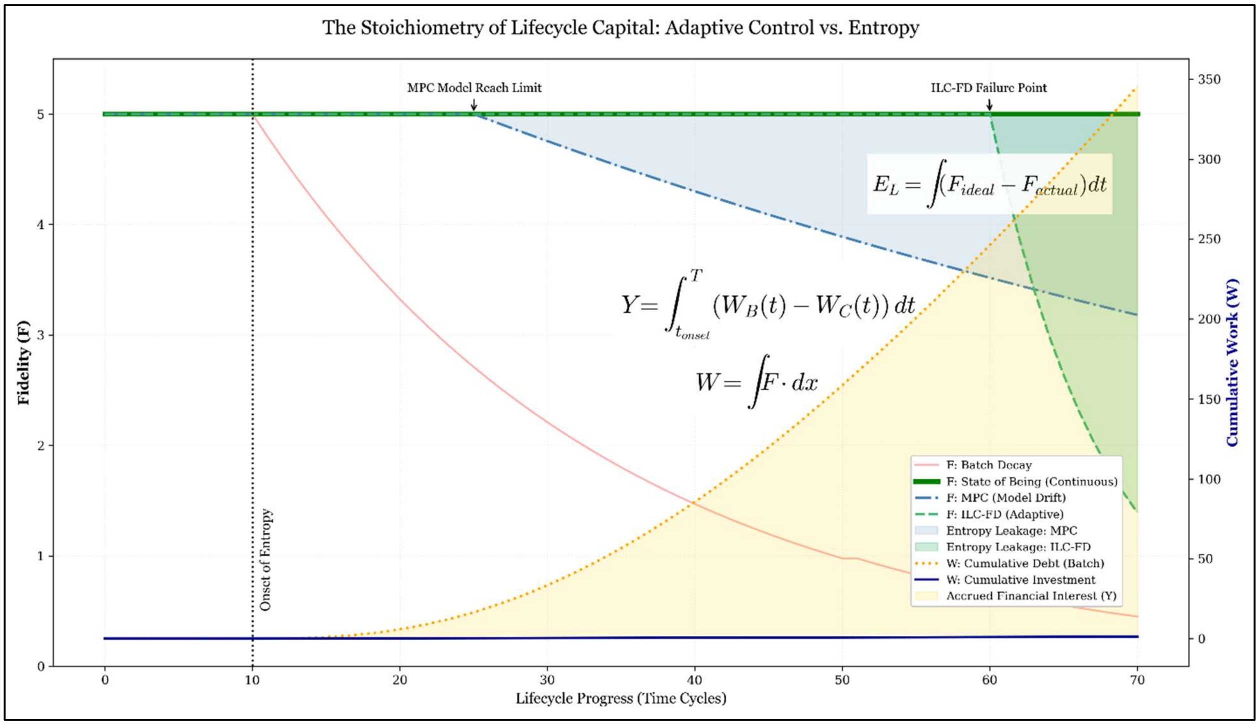

Figure 1: The Entropy of Control

Disrupting Entropy's Rate of Acceleration

Decay in a stoichiometric model adheres to the Law of Entropy, which indicates that disorder or unavailable energy of an isolated system cannot decelerate over a timescale suitable to a lifecycle. It represents the natural, irreversible transit from order to disorder, meaning that in any energy transfer in the absence of a control solution, some energy is dissipated as unusable heat. However, with a control solution applied, the Law of Entropy can be temporarily arrested by paying for order with Work (W).

While control can arrest entropy in the near term (see **Figure 1**) it ultimately cannot prevent it. The rate of decay (λ) is an unmovable constant, but the rate of acceleration as a function of time (t) is a variable, and it is this rate that control can disrupt. We can think of this disruption as a stay of execution that on a graph would reveal itself as a lateral rightward (t on x-axis) surge that stands proud of a downward and rightward curving trend reshaping it for a time to stretch rightward toward the red dotted curve before entropy resumes its inexorable track toward disorder (see **Figure 2**).

$$F(t) = F_0 + log_2(1 - \lambda \cdot t \cdot ln2)$$

Equation 1: Rate of Decay Equation

To disrupt the rate of acceleration, a Control-to-Decay ratio needs to be observed. Referencing **Table 2**, we set R_c to be the rate of correction and R_d be the rate of decay and only when $R_c > R_d$ is the relationship requirement for control to temporarily disrupt the rate of acceleration satisfied.

Ratio	C value	F value	Notes
$R_c < R_d$	$C=L_c$	$F<5$	Fidelity deficit: C (Command) increases to compensate. Strength Curve: Entropy > stoichiometric capacity
$R_c = R_d$	$C \rightarrow 0$	$F=5$	Equilibrium: the desired dynamic steady state Strength Curve: High Reserve (C≪Lc)
$R_c \approx R_d$	$C \rightarrow L_c$	$F<5$	Saturation: C is maxed out, but F deficit continues Strength Curve: Peak effort (C≈Lc)
$R_c > R_d$	$C>0$	$F>5$	Over-saturation: the max of F is 5 so >5 is wasteful. Strength Curve: Recovery: system has regained authority.
$R_c \ll R_d$	$C \rightarrow 0$	$F\Downarrow$	Fidelity at the point of no return: erodes at the rate of R_d Strength Curve: utility termination point triggers failsafe to prevent sunk cost decay.

Table 2: Corrective Ratios and their Stoichiometric Values

Control's Asymptotic Signature

A control solution is asymptotic, where the rate of corrective infusion (R_c in **Table 2**) counterbalances the rate of decay's acceleration over time, ensuring the system concerned maintains its post-catalytic orbit. As $C \rightarrow 0$ and $F \rightarrow 5$, R_c decreases commensurate with the instantaneous rate of decay. It is worth noting that the greater the R_c, the greater the resource support required for the capacity to deliver the corrective. This is the classic pattern of the strength curve continuum, where trimming is preferable to heroic recovery and by extension more efficient.

Entropy ultimately prevails, but control can delay entropy but at a cost that must be understood relative to the amount of time gained and capped at a ROI-style tolerance planned in advance. In our paradigm, as Fidelity (F) decreases, the precision of the system drops, requiring greater resource support to counter entropy and losing a larger proportion of the work (W) to the growing pool of disorder, which because it is state-dependent causes an increase of the decay constant (λ), rather like a train being rerouted to another track. This becomes a negative feedback loop that triggers each instance of the cam's translation and rotation.

The balance between control and entropy is governed in such a manner that Rate of Correction (R_c) must be greater than the current Rate of Decay (R_d) plus the accumulated Acceleration (A_d) of the entropic curve:

$$R_c \geq R_d + \int A_d \, dt$$

Equation 2: Control Balance Equation

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Natural decay follows half-life, where λ=0.50 and the timescale trend displays a long tail followed by a gentle but increasing slope (see the topmost entropic curve in **Figure 2**). However, in the case of mechanical systemic collapse we would expect to see a greater acceleration toward loss of control than is observed in natural decay. In this circumstance perhaps when λ=2.00, in practical terms entropy becomes usurious like a predatory high interest debt where the timescale trend shows a precipitous drop toward a fast and catastrophic failure.

Table 3 shows how the Rate of Decay (velocity) decreases in proportion to the Fidelity (F) remaining in accordance with the Law of Exponential Decay but that the Rate of Acceleration (frequency in the changes of velocity) increases geometrically, thereby bending the entropic curve downward. R_d informs the slope of entropic curves and A_d informs the slopes' accelerating descents. However, the table alone does not demonstrate the intervention of control or the limits of its reach. Behind the scenes, a Coefficient of Decay (λ_s) provides guidance on the timing and intensity of the correction, while determining the termination of control at a failsafe point. **Figure 3** illustrates a failsafe when the system concerned is returned to local automation.

Fidelity (F)	Standard Decay (R_d)	Rate of Acceleration (A_d)
5	10	2
4	8	4
3	6	8
2	4	16
1	2	32

Table 3: Accelerating Rates of Entropic Decay in Control

A real-time offset is the brass ring of control and is the only way to avoid phase shock. Keeping the rate of pump equal to the rate of drain ($R_p = R_d$), laminar flow is maintained in control, and the disruptive perturbations of phase shock are preempted, and the intricate state of stasis is preserved.

The Lifecycle Perspective of Control

By casting control as a cam in an entropic playlet (see **Figure 2**), we can imagine the benefits of control's physical expression as a time-variable radius and yet recognize its limitations. Control in the face of entropy will inevitably encounter a dynamic binding point, where the cam has engaged its maximal lift at a geometric tangent to the entropic curve. At this point, entropy becomes decoupled from control and resumes acceleration toward its natural rate of decay.

While the Law of Entropy is a universal constant, any entropic curve with a λ value other than the natural rate of a specific isolated system (λ = 0.50) is a mathematical model used to describe the degradation profile of a complex machine. While natural entropy provides the background radiation of decay, a controlled system operates within a modeled environment where a developing working understanding achieved through observation would relocate the system concerned to another λ value. By using these varying entropic curves as stochastic models rather than universal constants, we can more accurately predict how different levels of systemic disorder will eventually overwhelm control's work (W).

A comparison of Model Predictive Control (MPC) and Iterative Learning Control – Frequency Domain (ILC-FD) as they relate to entropy is revealing of their natures.

The Interaction of MPC on Entropic Curves

Because MPC is stoichiometric and reactive, the cam's movement is defined by keeping the system in a state of perfect alignment with its externally developed and immutable a priori model. MPC is strictly bound to its axis so there is no translation of the cam. The cam stays exactly where it was placed as the only possible point of intervention relative to entropy. Control via MPC is expressed as suite of micro-adjustments in the rotational (Ω) velocity of the cam. If MPC senses a slight dip in Fidelity (F) due to a surge in R_d, it speeds up or slows down the cam's rotation to maintain tight tolerance to the model's prediction.

MPC is sensitive to disturbances and works well in low noise applications but less so when noise increases beyond the sensitivity tolerance of the model that undergirds it. MPC observes a type of stoichiometric limit by rotating only as necessary. The cam cannot translate to a new position as this is outside of MPC's stoichiometric balancing logic.

The Interaction ILC-FD on Entropic Curves

Control in the face of entropy is not restricted to being stationary. In this cam paradigm, control via ILC-FD not only rotates on its axis but also moves curvilinearly within reasonable limits over time, with its position and orientation being indexed to the entropic timescale. As a translating cam, control pursues entropy by pushing entropy's curve (the solid red curve in **Figure 2**,) from the inside (the dotted red curve in **Figure 2**, which represents a preemptive intercept) to maintain engagement, much like an army in the face of a larger force taking advantage of interior lines while that advantage exists, until λ→∞ when control ultimately cams out and is flanked by entropy.

Control begins at F=5, where the applied contact point of control is at the minimum radius of the cam. As entropy pulls the system concerned toward the disorder, control must counter first with translation or re-positioning but then only as necessary with rotation of the cam to increase the radius. Control relocates along its interior line (black arrow in **Figure 2**) and then once the cam has turned 180° and is at its maximal lift - the apex of its rise (R_{max}) - fidelity will resume its entropic decrease. At this point, control has no lift remaining so it's position is untenable and the time has come for the cam to translate once again to do battle with entropy on new ground. Staying in place and turning the cam any further would result in either a bypass (loss of control) or a cam out (failure of reach), resulting in "an impact" on the base radius of the cam once 180° has been exceeded. The circumstances as described by **Equation 3** signals the need to reposition the cam to maintain the integrity of the interior line.

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$$\theta - 180^{\circ}\ AND\ \frac{dF}{dt} < 0$$

Equation 3: Control's Translation Criteria

The Stall Point (see **Figure 2**) is the moment where the steepness of the entropic slope exceeds the mechanical advantage of the cam's geometry before the cam's maximal radius is reached. The cam cannot be turned any further. At this intersection, control has been lost and the descent into a noisy disordered state is a fait accompli. In mechanics, this is known as valve float and a change in phase state is now inevitable.

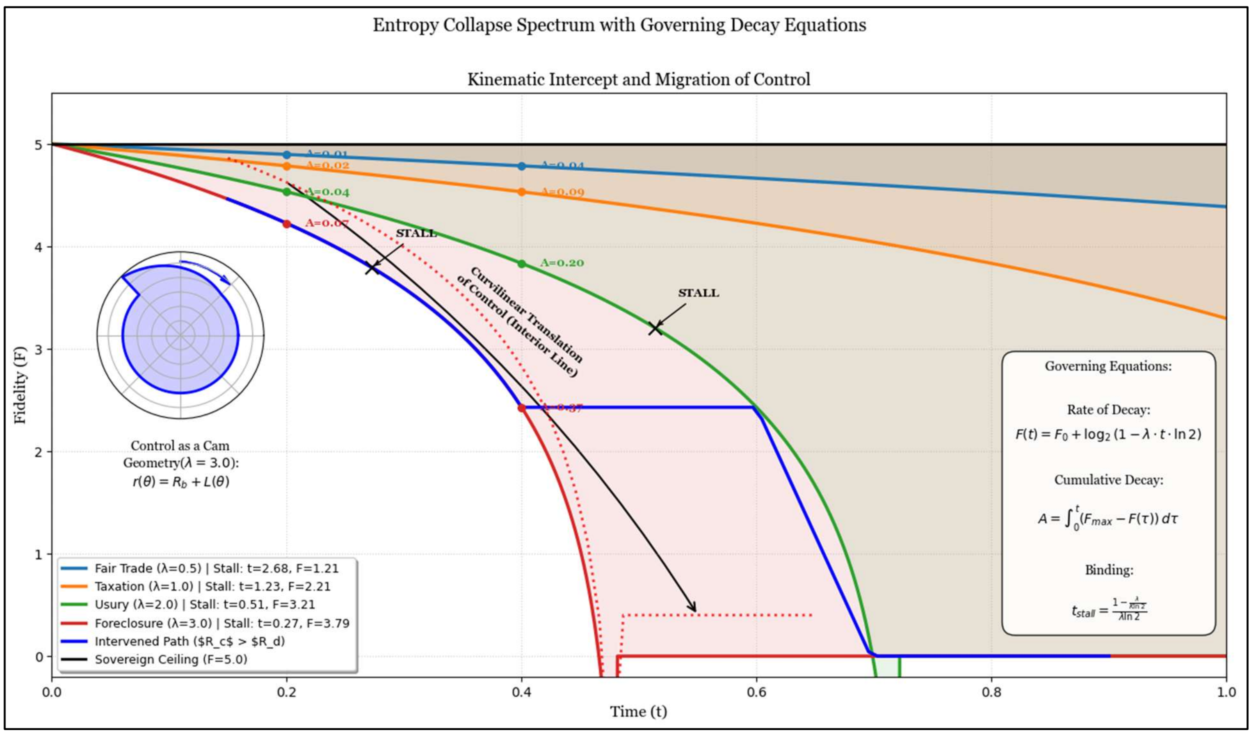

Figure 2: Control and the Entropy Collapse Spectrum

At the starting position (t=0, F→5), the cam is resting on its base circle. The radius is constant, the lift required is zero, and the Pressure Angle is 0°. There is no resistance because the entropy has not yet created a gap that needs to be filled. Control is present and positioned properly but not yet engaged with the entropic curve. As time goes on however and the entropic curve moves rightward (t ↑) and downward (F ↓), the cam must be repositioned along a curvilinear track and rotationally oriented appropriately to provide the lift required to push the asset back toward the F=5 ceiling. Moving rightward aspect of the translation represents the persistence of effort over time while moving downward aspect of the translation represents the increasing intensity of having control track the system concerned, attempting its retrieval while combatting the gravity well of decay.

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Efficiency and entropic delay have the same point of origin but different expressions. Efficiency measures how well the system concerned performs whereas entropic delay measures how much longer the system concerned can perform efficiently beyond its lifecycle expectancy (see the lateral entropic extension of the Intervened Path trend in **Figure 2**). Efficiency allows bought time to be used wisely, but only entropic delay buys that time in the first place. The influence of control on lifecycle extension deserves its own recognition.

<table>
<tr><th>State</th><th>t (Time)</th><th>F (Fidelity)</th><th>C (Control)</th><th>E (Effort/Slope)</th></tr>
<tr><td rowspan="2">Origin</td><td>t=0</td><td>$F \rightarrow 5$</td><td>C=0</td><td>E=0</td></tr>
<tr><td colspan="4">The Base Circle: No rotation, no translation. The system is at rest.</td></tr>
<tr><td rowspan="2">Interior Line</td><td>$0 < t < t_{stall}$</td><td>$F=F_0+\log_2(\ldots)$</td><td>$C=F_{max}-F(t)$</td><td>$E=dC/dt$</td></tr>
<tr><td colspan="4">The Rising Lobe: The cam is rotating and translating to bridge the gap.</td></tr>
<tr><td rowspan="2">Tangent</td><td>$t=t_{stall}$</td><td>F=Stall Point</td><td>C=Max Lift</td><td>E>=K</td></tr>
<tr><td colspan="4">The Cam-Out: The slope of decay exceeds the cam's mechanical advantage</td></tr>
</table>

Table 4: Interior Lines of Control v. Entropic Curve

The Limit of Control Relative to Entropy

All control models and techniques have a limit to their entropic reach and **Figure 3** illustrates a designed ILC-FD failsafe to relinquish control and cease delaying entropy any further, resulting in entropy leakage (the green shaded area in **Figure 3**), which can be measured. While control via ILC-FD in this illustration terminates at the cam's translational limit of $L_c = 0.06$ (6% of the system's total scale), a residual effect persists. This is represented by that subsection of the entropy leakage (the yellow shaded area) that exceeds the initiation of the failsafe. This illustrates the diminishing momentum of previous control interventions, the interval where the system concerned survives on the banked Fidelity of ILC-FD's inertial influence even as it is rapidly consumed by the unchecked acceleration of decay.

In contrast, **Figure 3** also illustrates that MPC will reach a threshold where the stochastic uncertainty described in Information Theory exceeds MPC's computational limit, which causes a gradual drift with Fidelity ($\downarrow$ F) decaying in direct proportion to the drift with greater entropy leakage (the sum of all the shaded areas) due to protracted elapsed time in a loss of control state. This stochastic computational stall is the counterpart to a planned failsafe, except that it is a silent signal that requires the drift to be observed in order to understand that a state of failure exists. Leaving awareness of a state of failure to chance in a control application is an abdication of the principles of control whereas integrating entropy to a designed failsafe condition is the last act of control's restraint that prioritizes the integrity of the system concerned over the continued operation of a once functioning control model that has since failed.

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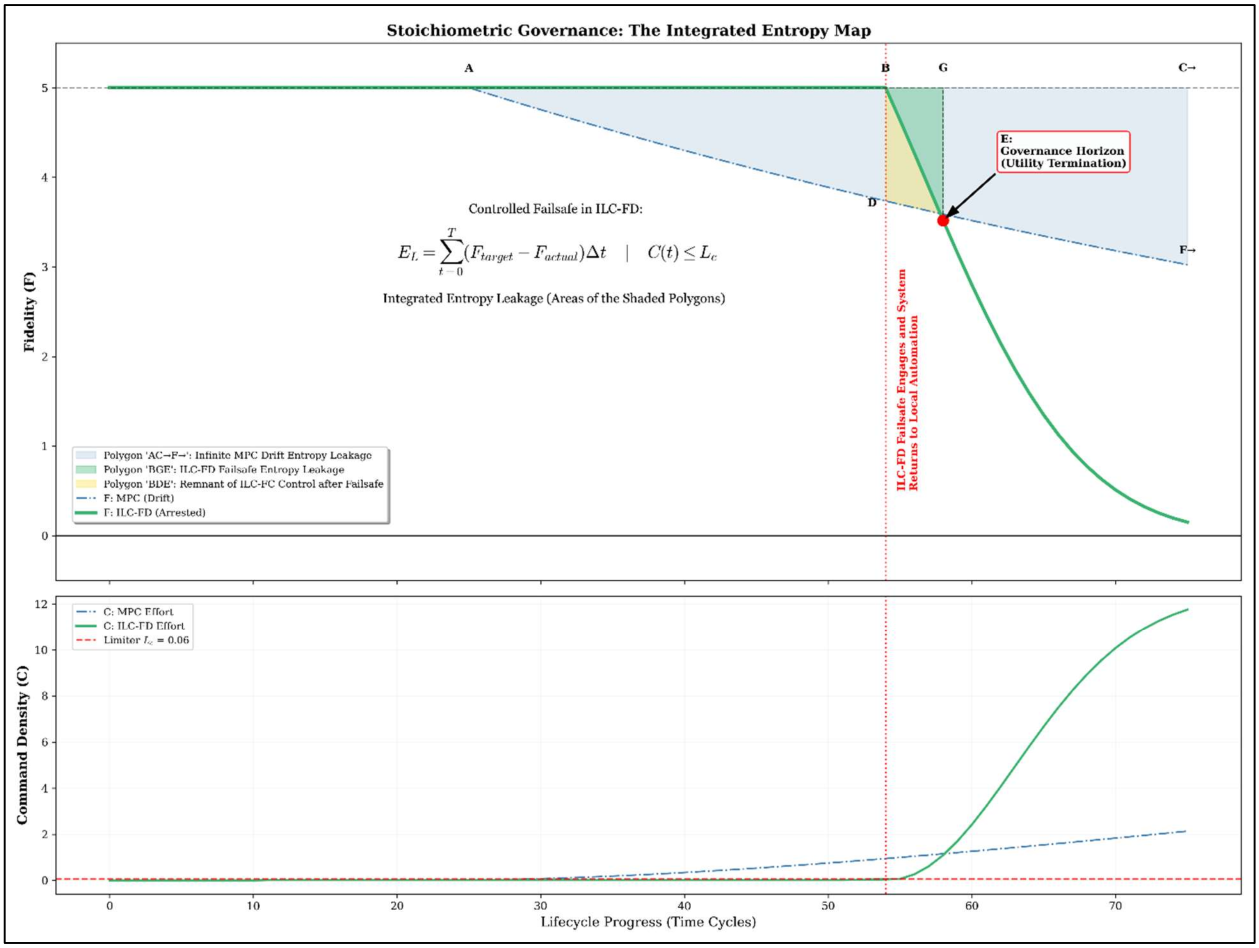

Figure 3: Limiting Entropic Leakage