Appendix D - Unified Harvest System Physics

Purpose:

To formalize the intake–separation–cleaning system using a unified state-variable framework, while remaining readable.

Not derivation-heavy.
Not abstract.

Structured.

D.1 Mass Flow Foundations

Area rate:

$$\dot{A} = vW$$

Biomass inflow:

$$\dot{m_{in}} = \dot{A}B$$

Grain flow:

$$\dot{m_g} = \dot{A}Y$$

Capacity constraint surface:

$$\dot{m_{in}} \leq C(\mu, f_{MOG}, \rho_m)$$

Key insight:
Capacity is not constant. It collapses as mat density and moisture rise.

D.2 The Unified Intake State

Define intake vector:

$$I = (f_f, f_a, f_{MOG}, \rho_m, \sigma_p)$$

Where:

- f_f = free grain fraction
- f_a = attached grain fraction

- f_{MOG} = material other than grain (non-grain fraction)
- ρ_m = feeder mat density proxy
- σ_p = particle size / aerodynamic variance

Each header defines:

$I = H(\text{header settings,crop state})$

Downstream systems operate on I, not directly on header mechanics.

This becomes the intellectual anchor of Appendix D.

D.3 Header-Specific Governing Indices

Instead of listing all equations, define the dominant index for each header:

Grain Platform
- Reel index λ
- Impact impulse I
- Shatter probability logistic model

Corn Header
- Pull-to-strength group
- Bending moment at head
- Row capture efficiency

Milo Header
- Support geometry constraint
- Cut shock energy
- Intake speed ratio

Then show:

$H_{platform} \rightarrow I$
$H_{corn} \rightarrow I$
$H_{milo} \rightarrow I$

This section proves header choice shifts the feasible region downstream.

D.4 Threshing as Energy Saturation

Specific thresh energy:

$E_s = f(u_r, c, \rho_m)$

Thresh completeness:

$F_{thresh} = 1 - e^{-kE_s}$

Unthreshed:

$1 - F_{thresh}$

Bridge term:

$E_{required} = f(f_a$,pre-fracture)

Key insight:
Higher pre-fracture lowers required energy but may increase shoe load.

D.5 Separation as Residence-Time Process

Residence time:

$$\tau = \frac{L_s}{u_a}$$

Separation efficiency:

$F_{sep} = 1 - e^{-k\tau}$

Separation loss:

$L_{sep} = (1 - F_{sep})F_{thresh}$

Important:
Mat density modifies effective τ.

D.6 Cleaning as Terminal Velocity Sorting

Terminal velocity condition:

$U \gtrless V_t$

Carryout risk:

$P_{carry} = \sigma(U - V_t)$

Sieve flux constraint:

$$\phi = \frac{\dot{m}_g}{A_{sieve}}$$

Overload factor:

ϕ/ϕ_{crit}

Tailings feedback increases effective energy exposure.

D.7 Loss Accounting Without Double Counting

$L = L_h + (1 - L_h)L_{ts} + (1 - L_h)(1 - L_{ts})L_c$

This is clean and correct.

D.8 Optimization Framing

Decision vector:

$\theta = (v, \lambda \text{ or pull index}, u_r, c, U, \alpha)$

Objective:

Minimize:

$L(\theta)$

Subject to:

- Capacity constraint
- Damage constraint
- Machine limits

Key structural conclusion:

Each header shifts the feasible solution region by altering I.