XA103 Adaptive-Cycle Engine (NGAP) ? Deep E

Document objective: Deliver a 30?40 page, technically dense engineering report on XA103-class adaptive-cycle propulsion, with strict separation between public program facts, first-principles analysis, and constrained inference where public data is incomplete.

1. Epistemic framework and report discipline

1.1 Data classes used throughout

â¢ **Class A (Program-fact):** Publicly acknowledged AETP/NGAP context, demonstrator existence, and broad directional claims about fuel, thrust, and thermal capacity improvements.
â¢ **Class B (Physics-derivable):** Statements deduced directly from gas-turbine thermodynamics, compressible flow, control-volume analysis, and aircraft mission equations.
â¢ **Class C (Constrained inference):** XA103-specific engineering estimates consistent with Class A+B but not publicly certified.

1.2 Why XA103 absolute numbers remain uncertain

No open release provides complete engine deck data (thrust lapse tables, corrected flow maps, surge lines, cooling-flow splits, transient schedules, electrical extraction maps, component life models). Therefore, rigorous reporting must emphasize equation-level mechanisms and mission-level sensitivity analysis rather than pretending to know classified point values.

1.3 Notation

â¢ $\dot m$: mass flow; $\dot m_f$: fuel flow; f: fuel-to-air ratio.
â¢ V_0: flight speed; V_j: exhaust speed; F: net thrust.
â¢ π_c: compressor pressure ratio; T_{t4}: combustor exit total temperature.
â¢ η_{th}: thermal efficiency; η_p: propulsive efficiency; $\eta_o=\eta_{th}\eta_p$.
â¢ $\beta_{eff}=\dot m_{bypass,total}/\dot m_{core}$: effective bypass ratio including adaptive stream.
â¢ c_T: thrust-specific fuel consumption-like parameter for mission equations.

2. Program context and development status

2.1 AETP to NGAP transition

AETP validated adaptive-cycle fighter propulsion architecture through full-scale demonstrators (publicly associated with GE XA100 and Pratt XA101). NGAP is the follow-on propulsion path aligned to NGAD mission demands: larger combat radius, higher sustained specific excess power, and materially higher thermal/power margins for onboard mission systems.

2.2 XA103 placement

In open reporting, XA103 is associated with Pratt & Whitney?s NGAP adaptive-cycle workstream. What is defensible: XA103 is not an in-service fielded engine; it is a development-stage architecture in a classified/partially disclosed acquisition context.

2.3 Decision-relevant implication

Program state should be interpreted as **technology-risk retirement progressing faster than complete public transparency**. This is normal for sixth-generation propulsion: survivability, thermal architecture, and platform-integration details are operationally sensitive.

3. Adaptive-cycle thermodynamic foundations

3.1 Governing thrust relation

For a mixed-flow jet control volume:

$$
F = \dot m_j V_j - \dot m_0 V_0 + (p_e-p_0)A_e
$$

Adaptive-cycle design manipulates $\dot m_j$, V_j, and effective pressure matching via variable geometry to satisfy contradictory mission requirements.

3.2 TSFC objective

$$
\mathrm{TSFC}=\frac{\dot m_f}{F}
$$

Combat aircraft mission effectiveness is often more sensitive to TSFC over profile segments than to peak brochure thrust, because TSFC controls fuel logistics, tanker burden, and persistence.

3.3 Propulsive efficiency trend

Idealized relation:

$$
\eta_p \approx \frac{2}{1+V_j/V_0}
$$

At cruise, reducing V_j/V_0 improves η_p. Adaptive engines do this by raising effective bypass participation. At combat acceleration, engine shifts toward higher specific thrust and accepts reduced η_p locally for excess thrust.

3.4 Thermal efficiency levers

Classical levers remain: compressor ratio π_c, component efficiencies, allowable T_{t4}, and cooling-flow penalties. Adaptive-cycle architectures do not repeal these laws; they provide an additional **flowpath degree of freedom** to alter where and how entropy is generated and rejected across mission points.

4. Three-stream architecture and dynamic bypass mechanics

4.1 Canonical flow partition

1. Core stream (compressor-combustor-turbine).
2. Primary bypass stream (fan bypass).
3. Adaptive third stream (controllable mass-flow/temperature channel).

4.2 Why the third stream is transformational

â¢ It allows mission-point-dependent β_{eff} without fixed geometric compromise.
â¢ It provides controllable heat sink capacity independent of only fuel temperature margin.
â¢ It can assist infrared management via mixing/temperature conditioning strategies.
â¢ It decouples, to a degree, thrust generation from thermal rejection tasks.

4.3 Matching and operability constraints

Dynamic bypass operation is constrained by coupled subsystem limits:
â¢ compressor surge margin under rapidly changing corrected flow,
â¢ turbine work split and shaft acceleration limits,
â¢ nozzle choking and pressure ratio constraints,

â¢ actuator bandwidth and position uncertainty,
â¢ FADEC scheduling under simultaneous pilot-throttle and mission-power transients.

4.4 Control design consequence

Adaptive-cycle control is fundamentally multivariable (MIMO). It requires model-based scheduling, observer-supported state estimation, and robust constraint handling to avoid operability excursions during high dynamic demand.

5. Fluid dynamics and turbomachinery detail

5.1 Fan/compressor map migration

Variable geometry and adaptive stream scheduling move operating points across compressor maps. Benefit is flexibility; cost is increased need for accurate map-based control and greater sensitivity to inlet distortion and actuator lag.

5.2 Corrected flow and speed

Corrected quantities ($\dot m\sqrt{T_t}/P_t$, $N/\sqrt{T_t}$) govern map similarity. Adaptive engines deliberately reshape corrected flow split between core and bypass streams; this is the mathematical core of ?dynamic bypass ratio.?

5.3 Nozzle and mixer implications

Nozzle area scheduling and mixing losses become first-order. A control law that improves TSFC but incurs poor nozzle matching can lose net benefit through pressure-thrust penalties and stability margin erosion.

5.4 Boundary-layer and distortion sensitivity

Installed performance depends on inlet distortion tolerance. Adaptive engines must preserve surge margin under realistic distortion patterns from maneuvers and high-angle conditions.

6. Materials and hot-section engineering

6.1 CMC role

Ceramic matrix composites are critical for improving temperature capability at reduced density and potentially lower cooling-air requirements for specific components.

6.2 Cooling-air economics

Every unit of bleed used to cool hot parts is unavailable for propulsive work. Therefore, materials that reduce cooling demand can increase effective cycle efficiency and power available for both thrust and electrical extraction.

6.3 Durability trade

Temperature margin can be traded among:
â¢ higher performance at equal life,
â¢ equal performance at longer life,
â¢ increased thermal off-take capability at acceptable life.

6.4 Manufacturing challenge

CMC benefit is contingent on repeatable manufacturing quality, coating durability, and field maintainability. Lifecycle economics may dominate acquisition choices as much as peak cycle performance.

7.1 Why this is central

For sixth-generation aircraft, mission systems can become thermal-limited before aerodynamics or fuel-limited in specific operating regions. Propulsion is thus an integrated thermal utility, not only a thrust source.

7.2 Heat sources

â¢ radar (AESA) duty cycles,
â¢ electronic warfare transmit/receive loads,
â¢ onboard processing and AI compute modules,
â¢ high-power datalinks and aperture electronics,
â¢ potential directed-energy subsystems.

7.3 Heat sink pathways

â¢ fuel as transient heat sink (bounded by coking/temperature limits),
â¢ third-stream airflow as controllable sink,
â¢ exchanger network and environmental control loops,
â¢ structural thermal capacitance over short intervals.

7.4 Architecture insight

Adaptive-cycle engines expand sink management state-space: they can trade flowpath configuration against thermal demand in real time, reducing mission-system derate risk.

8. High electrical power extraction and directed-energy relevance

8.1 Fundamental coupling

Electrical extraction increases shaft load, which perturbs spool dynamics and available thrust margin. Without adaptive-cycle headroom, large extraction can induce unacceptable propulsion penalties.

8.2 Required performance maps (what must be measured)

A serious XA103 evaluation must include:
â¢ extraction power vs thrust penalty maps,
â¢ extraction power vs surge margin maps,
â¢ thermal rejection limit maps vs ambient/altitude/Mach,
â¢ transient response maps under coupled throttle+power steps.

8.3 Operational significance

Military investment is driven by expectation that future kill chains are constrained by onboard energy throughput. Engines enabling higher continuous power with manageable penalty directly enable next-generation mission systems.

9. Signature implications (infrared and thermal observability)

9.1 IR detectability drivers

IR vulnerability depends on plume temperature distribution, hotspot exposure, emissivity, and atmospheric propagation. Increased onboard heat worsens this problem unless managed at source and sink levels.

9.2 Adaptive-cycle leverage

Third-stream routing and mixing can provide extra control authority for plume temperature conditioning and local hotspot management compared to fixed two-stream configurations.

9.3 Limits

Engine architecture alone cannot guarantee low IR observability; nozzle geometry, airframe integration, coatings, and mission profile all remain co-equal determinants.

10. Mission performance modeling

10.1 Breguet framework

Jet range scaling:

$$
R \sim \frac{V}{c_T}\left(\frac{L}{D}\right)\ln\left(\frac{W_i}{W_f}\right)
$$

A reduction in c_T (TSFC-like) improves range and persistence nonlinearly with weight fraction and drag characteristics.

10.2 Sensitivity setup

To avoid false precision, scenario sweeps are used instead of single-point claims. Baseline normalized range multiplier:

$$
M_R = \frac{R_{new}}{R_{base}} = \frac{(V/c_T)(L/D)\ln(W_i/W_f)_{new}}{(V/c_T)(L/D)\ln(W_i/W_f)_{base}}
$$

For first-order illustration, hold $V, L/D, W_i/W_f$ terms approximately constant and vary c_T. Then $M_R \approx c_{T,base}/c_{T,new}$.

10.3 Parametric sweep A: TSFC improvement-only multipliers

Assumption set A isolates propulsion effect only (other terms held constant).

TSFC improvement	Range/Persistence multiplier
5%	1.053x
6%	1.064x
7%	1.075x
8%	1.087x
9%	1.099x
10%	1.111x
11%	1.124x
12%	1.136x
13%	1.149x
14%	1.163x
15%	1.176x
16%	1.190x
17%	1.205x
18%	1.220x
19%	1.235x
20%	1.250x
21%	1.266x
22%	1.282x
23%	1.299x

24%	1.316x
25%	1.333x
26%	1.351x
27%	1.370x
28%	1.389x
29%	1.408x
30%	1.429x
31%	1.449x
32%	1.471x
33%	1.493x
34%	1.515x
35%	1.538x

10.4 Parametric sweep B: coupled TSFC and drag-ratio sensitivity

Assumption set B adds L/D variation to represent integration uncertainty.

TSFC improvement	L/D delta	Approx multiplier
10%	-8%	1.022x
10%	-4%	1.067x
10%	+0%	1.111x
10%	+4%	1.156x
10%	+8%	1.200x
15%	-8%	1.082x
15%	-4%	1.129x
15%	+0%	1.176x
15%	+4%	1.224x
15%	+8%	1.271x
20%	-8%	1.150x
20%	-4%	1.200x
20%	+0%	1.250x
20%	+4%	1.300x
20%	+8%	1.350x
25%	-8%	1.227x
25%	-4%	1.280x
25%	+0%	1.333x
25%	+4%	1.387x
25%	+8%	1.440x
30%	-8%	1.314x
30%	-4%	1.371x
30%	+0%	1.429x
30%	+4%	1.486x
30%	+8%	1.543x

10.5 Parametric sweep C: fuel fraction / reserve policy sensitivity

Using Breguet log term, reserve policy can materially reduce apparent radius gain despite better TSFC.

Wi/Wf baseline	Wi/Wf improved	Log-term ratio
1.25	1.26	1.036x
1.25	1.27	1.071x
1.25	1.28	1.106x
1.25	1.29	1.141x

1.25	1.30	1.176x
1.30	1.31	1.029x
1.30	1.32	1.058x
1.30	1.33	1.087x
1.30	1.34	1.116x
1.30	1.35	1.144x
1.35	1.36	1.025x
1.35	1.37	1.049x
1.35	1.38	1.073x
1.35	1.39	1.097x
1.35	1.40	1.121x
1.40	1.41	1.021x
1.40	1.42	1.042x
1.40	1.43	1.063x
1.40	1.44	1.084x
1.40	1.45	1.104x
1.45	1.46	1.018x
1.45	1.47	1.037x
1.45	1.48	1.055x
1.45	1.49	1.073x
1.45	1.50	1.091x
1.50	1.51	1.016x
1.50	1.52	1.033x
1.50	1.53	1.049x
1.50	1.54	1.065x
1.50	1.55	1.081x

10.6 Key modeling takeaway

A 20?25% class TSFC improvement can plausibly deliver a double-digit to large-double-digit mission-radius increase depending on drag and reserve policy. The exact result is aircraft- and CONOPS-specific, but directionality is robust.

11. Tactical consequences (first-order operational layer)

11.1 Persistence and station time

Higher mission fuel efficiency shifts time-on-station upward for fixed launch fuel, improving engagement opportunities and sensor dwell.

11.2 Supercruise endurance

Adaptive cycle can sustain high-speed segments with less punitive fuel burn than conventional low-bypass architectures operated off their optimal mission point.

11.3 Payload-energy coexistence

The engine can better support concurrent propulsion and electrical loads, which matters for high-duty EW/radar operations during kinematically demanding phases.

12. Strategic consequences (second-order)

12.1 Tanker dependence and vulnerability geometry

Reduced fighter refueling frequency enables farther standoff refueling tracks, lower tanker exposure, and increased flexibility in campaign design.

12.2 Theater fuel logistics

Fuel throughput reduction eases pressure on vulnerable logistics nodes, increasing campaign resilience under interdiction risk.

12.3 Force package economics

If support burden per strike effect declines, fewer enabling sorties are required for equivalent mission output, improving force elasticity.

13. Third-order system effects and doctrine migration

13.1 Airframe design-space shift

Greater propulsion thermal/electrical margin allows architects to expand sensor aperture power, onboard processing, and future payload integration options.

13.2 Command-and-control elasticity

Longer endurance and lower tanker coupling increase retasking freedom and reduce timing fragility in distributed operations.

13.3 Deterrence signaling

Practical reach from existing basing can increase without immediate tanker-forwarding, altering peacetime signaling and crisis response posture.

14. Comparative architecture discussion: fixed-cycle vs adaptive-cycle

Attribute	Fixed low-bypass AB turbofan	Adaptive-cycle three-stream
Cruise propulsive efficiency	Limited by fixed low bypass	Improved via higher effective bypass mode
High-thrust combat mode	Strong	Comparable or improved with mode switching
Thermal sink flexibility	More constrained	Expanded via adaptive stream and control authority
Electrical extraction headroom	Lower at equal penalty	Higher achievable envelope (architecture-dependent)
Control complexity	Moderate	High (MIMO scheduling, more constraints)
Mechanical complexity	Lower	Higher (variable geometry, actuators)
Maintainability burden	Lower baseline	Potentially higher unless mitigated by design/diagnostics

15. Engineering risk register (deep technical)

Risk	Mechanism	Mitigation direction
Variable-geometry fatigue	Actuator/linkage wear under high-cycle fighter transients	Redundant actuation, prognostics, duty-cycle-aware control
Surge/stall excursions	Aggressive flow split changes and inlet distortion	Robust scheduling with margin observers and envelope guards
Thermal saturation	High mission-system duty cycle exceeds sink capacity	Adaptive sink scheduling + thermal-aware mission management

Nozzle/mixer losses	Poor matching erodes theoretical cycle gain	High-fidelity calibration and installation co-design
CMC durability scatter	Manufacturing variability/coating degradation	Process control + inspection + life model updates
Power extraction transients	Electrical steps destabilize spool dynamics	Integrated power-propulsion transient management
Maintainability burden	More LRUs/mechanisms increase downtime	Modular design + digital twin diagnostics
Integration concurrency	Airframe-propulsion interface changes late	Early digital integration and hardware-in-loop validation

16. Verification and validation framework (what evidence is required)

16.1 Engine-only evidence

1. Full envelope deck (thrust, TSFC, surge margin, acceleration times).
2. Electrical extraction maps vs thrust penalty and operability margins.
3. Thermal rejection maps vs ambient/Mach/altitude and duty cycles.
4. Durability statistics for variable hardware and hot-section components.

16.2 Installed evidence

1. Inlet distortion impact characterization.
2. Nozzle integration and drag/thrust bookkeeping.
3. Mission profile fuel and radius measurements with realistic reserves.
4. Signature measurements (plume/hotspot) under representative conditions.

16.3 Campaign-level evidence

1. Tanker-sortie deltas for fixed objective sets.
2. Logistics throughput reductions and sortie generation resilience.
3. Mission-system duty-cycle sustainability with no thermal derate.

17. Commercial and cross-domain spillover assessment

17.1 High-confidence spillovers

â¢ advanced CMC manufacturing and qualification workflows,
â¢ model-based health monitoring and adaptive control practices,
â¢ compact high-capacity thermal exchange methods.

17.2 Limited near-term spillovers

Full military adaptive-cycle complexity is unlikely to transfer directly to subsonic civil fleets due to cost/maintenance economics.

17.3 Potential supersonic niche

If commercial supersonic mission economics mature, variable-cycle concepts could become attractive where wide envelope efficiency matters.

18. Detailed appendix A: equation set and derivation notes

A.1 Derivation note 1

For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

A.2 Derivation note 2

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A.18 Derivation note 18

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For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

A.35 Derivation note 35

For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

A.36 Derivation note 36

For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

A.37 Derivation note 37

For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

A.38 Derivation note 38

For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

A.39 Derivation note 39

For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

A.40 Derivation note 40

For adaptive-cycle analysis, enforce simultaneous conservation of mass, momentum, and energy across each stream with matching constraints at mixer and nozzle boundaries. Include corrected-flow similarity transforms for map consistency and account for bleed/cooling and extraction terms in turbine work balance. A practical model must couple spool dynamics, actuator dynamics, and mission power demand trajectories; steady-state cycle points alone are insufficient for fighter-relevant performance claims.

19. Detailed appendix B: mission and extraction scenario matrix

Scenario ID	TSFC delta	Thrust delta	Electrical extraction stress	Thermal stress	Assessment
S001	10%	5%	Low	Low	Outcome sensitive to integration and control quality
S002	10%	5%	Low	Med	Outcome sensitive to integration and control quality
S003	10%	5%	Low	High	Outcome sensitive to integration and control quality
S004	10%	5%	Med	Low	Outcome sensitive to integration and control quality
S005	10%	5%	Med	Med	Outcome sensitive to integration and control quality
S006	10%	5%	Med	High	Outcome sensitive to integration and control quality
S007	10%	5%	High	Low	Outcome sensitive to integration and control quality
S008	10%	5%	High	Med	Outcome sensitive to integration and control quality
S009	10%	5%	High	High	High risk of derate without superior sink control
S010	10%	10%	Low	Low	Outcome sensitive to integration and control quality
S011	10%	10%	Low	Med	Outcome sensitive to integration and control quality
S012	10%	10%	Low	High	Outcome sensitive to integration and control quality
S013	10%	10%	Med	Low	Outcome sensitive to integration and control quality
S014	10%	10%	Med	Med	Outcome sensitive to integration and control quality
S015	10%	10%	Med	High	Outcome sensitive to integration and control quality
S016	10%	10%	High	Low	Outcome sensitive to integration and control quality
S017	10%	10%	High	Med	Outcome sensitive to integration and control quality
S018	10%	10%	High	High	High risk of derate without superior sink control
S019	10%	12%	Low	Low	Outcome sensitive to integration and control quality
S020	10%	12%	Low	Med	Outcome sensitive to integration and control quality
S021	10%	12%	Low	High	Outcome sensitive to integration and control quality
S022	10%	12%	Med	Low	Outcome sensitive to integration and control quality
S023	10%	12%	Med	Med	Outcome sensitive to integration and control quality
S024	10%	12%	Med	High	Outcome sensitive to integration and control quality
S025	10%	12%	High	Low	Outcome sensitive to integration and control quality
S026	10%	12%	High	Med	Outcome sensitive to integration and control quality
S027	10%	12%	High	High	High risk of derate without superior sink control
S028	15%	5%	Low	Low	Outcome sensitive to integration and control quality
S029	15%	5%	Low	Med	Outcome sensitive to integration and control quality
S030	15%	5%	Low	High	Outcome sensitive to integration and control quality
S031	15%	5%	Med	Low	Outcome sensitive to integration and control quality
S032	15%	5%	Med	Med	Outcome sensitive to integration and control quality
S033	15%	5%	Med	High	Outcome sensitive to integration and control quality
S034	15%	5%	High	Low	Outcome sensitive to integration and control quality
S035	15%	5%	High	Med	Outcome sensitive to integration and control quality
S036	15%	5%	High	High	High risk of derate without superior sink control
S037	15%	10%	Low	Low	Outcome sensitive to integration and control quality
S038	15%	10%	Low	Med	Outcome sensitive to integration and control quality
S039	15%	10%	Low	High	Outcome sensitive to integration and control quality

S040	15%	10%	Med	Low	Outcome sensitive to integration and control quality
S041	15%	10%	Med	Med	Outcome sensitive to integration and control quality
S042	15%	10%	Med	High	Outcome sensitive to integration and control quality
S043	15%	10%	High	Low	Outcome sensitive to integration and control quality
S044	15%	10%	High	Med	Outcome sensitive to integration and control quality
S045	15%	10%	High	High	High risk of derate without superior sink control
S046	15%	12%	Low	Low	Outcome sensitive to integration and control quality
S047	15%	12%	Low	Med	Outcome sensitive to integration and control quality
S048	15%	12%	Low	High	Outcome sensitive to integration and control quality
S049	15%	12%	Med	Low	Outcome sensitive to integration and control quality
S050	15%	12%	Med	Med	Outcome sensitive to integration and control quality
S051	15%	12%	Med	High	Outcome sensitive to integration and control quality
S052	15%	12%	High	Low	Outcome sensitive to integration and control quality
S053	15%	12%	High	Med	Outcome sensitive to integration and control quality
S054	15%	12%	High	High	High risk of derate without superior sink control
S055	20%	5%	Low	Low	Outcome sensitive to integration and control quality
S056	20%	5%	Low	Med	Outcome sensitive to integration and control quality
S057	20%	5%	Low	High	Outcome sensitive to integration and control quality
S058	20%	5%	Med	Low	Outcome sensitive to integration and control quality
S059	20%	5%	Med	Med	Outcome sensitive to integration and control quality
S060	20%	5%	Med	High	Outcome sensitive to integration and control quality
S061	20%	5%	High	Low	Outcome sensitive to integration and control quality
S062	20%	5%	High	Med	Outcome sensitive to integration and control quality
S063	20%	5%	High	High	Outcome sensitive to integration and control quality
S064	20%	10%	Low	Low	Outcome sensitive to integration and control quality
S065	20%	10%	Low	Med	Outcome sensitive to integration and control quality
S066	20%	10%	Low	High	Outcome sensitive to integration and control quality
S067	20%	10%	Med	Low	Outcome sensitive to integration and control quality
S068	20%	10%	Med	Med	Outcome sensitive to integration and control quality
S069	20%	10%	Med	High	Outcome sensitive to integration and control quality
S070	20%	10%	High	Low	Outcome sensitive to integration and control quality
S071	20%	10%	High	Med	Outcome sensitive to integration and control quality
S072	20%	10%	High	High	Outcome sensitive to integration and control quality
S073	20%	12%	Low	Low	Outcome sensitive to integration and control quality
S074	20%	12%	Low	Med	Outcome sensitive to integration and control quality
S075	20%	12%	Low	High	Outcome sensitive to integration and control quality
S076	20%	12%	Med	Low	Outcome sensitive to integration and control quality
S077	20%	12%	Med	Med	Outcome sensitive to integration and control quality
S078	20%	12%	Med	High	Outcome sensitive to integration and control quality
S079	20%	12%	High	Low	Outcome sensitive to integration and control quality
S080	20%	12%	High	Med	Outcome sensitive to integration and control quality
S081	20%	12%	High	High	Outcome sensitive to integration and control quality
S082	25%	5%	Low	Low	Outcome sensitive to integration and control quality
S083	25%	5%	Low	Med	Outcome sensitive to integration and control quality
S084	25%	5%	Low	High	Outcome sensitive to integration and control quality
S085	25%	5%	Med	Low	Outcome sensitive to integration and control quality
S086	25%	5%	Med	Med	Outcome sensitive to integration and control quality
S087	25%	5%	Med	High	Outcome sensitive to integration and control quality
S088	25%	5%	High	Low	Outcome sensitive to integration and control quality
S089	25%	5%	High	Med	Outcome sensitive to integration and control quality
S090	25%	5%	High	High	Outcome sensitive to integration and control quality
S091	25%	10%	Low	Low	Strong mission leverage likely

S092	25%	10%	Low	Med	Strong mission leverage likely
S093	25%	10%	Low	High	Strong mission leverage likely
S094	25%	10%	Med	Low	Strong mission leverage likely
S095	25%	10%	Med	Med	Strong mission leverage likely
S096	25%	10%	Med	High	Strong mission leverage likely
S097	25%	10%	High	Low	Outcome sensitive to integration and control quality
S098	25%	10%	High	Med	Outcome sensitive to integration and control quality
S099	25%	10%	High	High	Outcome sensitive to integration and control quality
S100	25%	12%	Low	Low	Strong mission leverage likely
S101	25%	12%	Low	Med	Strong mission leverage likely
S102	25%	12%	Low	High	Strong mission leverage likely
S103	25%	12%	Med	Low	Strong mission leverage likely
S104	25%	12%	Med	Med	Strong mission leverage likely
S105	25%	12%	Med	High	Strong mission leverage likely
S106	25%	12%	High	Low	Outcome sensitive to integration and control quality
S107	25%	12%	High	Med	Outcome sensitive to integration and control quality
S108	25%	12%	High	High	Outcome sensitive to integration and control quality
S109	30%	5%	Low	Low	Outcome sensitive to integration and control quality
S110	30%	5%	Low	Med	Outcome sensitive to integration and control quality
S111	30%	5%	Low	High	Outcome sensitive to integration and control quality
S112	30%	5%	Med	Low	Outcome sensitive to integration and control quality
S113	30%	5%	Med	Med	Outcome sensitive to integration and control quality
S114	30%	5%	Med	High	Outcome sensitive to integration and control quality
S115	30%	5%	High	Low	Outcome sensitive to integration and control quality
S116	30%	5%	High	Med	Outcome sensitive to integration and control quality
S117	30%	5%	High	High	Outcome sensitive to integration and control quality
S118	30%	10%	Low	Low	Strong mission leverage likely
S119	30%	10%	Low	Med	Strong mission leverage likely
S120	30%	10%	Low	High	Strong mission leverage likely
S121	30%	10%	Med	Low	Strong mission leverage likely
S122	30%	10%	Med	Med	Strong mission leverage likely
S123	30%	10%	Med	High	Strong mission leverage likely
S124	30%	10%	High	Low	Outcome sensitive to integration and control quality
S125	30%	10%	High	Med	Outcome sensitive to integration and control quality
S126	30%	10%	High	High	Outcome sensitive to integration and control quality
S127	30%	12%	Low	Low	Strong mission leverage likely
S128	30%	12%	Low	Med	Strong mission leverage likely
S129	30%	12%	Low	High	Strong mission leverage likely
S130	30%	12%	Med	Low	Strong mission leverage likely
S131	30%	12%	Med	Med	Strong mission leverage likely
S132	30%	12%	Med	High	Strong mission leverage likely
S133	30%	12%	High	Low	Outcome sensitive to integration and control quality
S134	30%	12%	High	Med	Outcome sensitive to integration and control quality
S135	30%	12%	High	High	Outcome sensitive to integration and control quality

20. Detailed appendix C: terminology and subsystem glossary

â¢ **Adaptive stream:** Third controllable flow stream used for bypass/thermal management flexibility.

â¢ **Corrected flow:** Mass flow normalized by total temperature and pressure for map similarity.

â¢ **Surge margin:** Distance from compressor operating line to surge line, critical for operability.

â¢ **IPTMS:** Integrated Power and Thermal Management System coupling propulsion, power, and cooling.

â¢ **Specific thrust:** Net thrust per unit core or inlet mass flow, depending on convention.

â¢ **TSFC:** Fuel flow per unit thrust, key mission efficiency metric for jets.

â¢ **Installed performance:** Engine performance after inlet/nozzle/airframe integration losses/gains.

â¢ **Power off-take:** Mechanical shaft power diverted to generators for electrical loads.

â¢ **Thermal derate:** Forced reduction of mission-system or propulsion performance due to heat limits.

â¢ **Digital twin:** Model-based runtime and lifecycle representation used for diagnostics/prognostics.

21. Bottom-line synthesis for decision makers

XA103-class propulsion is strategically significant because it reframes engine value from single-axis thrust optimization to multi-axis platform energy optimization (thrust + fuel + electrical power + thermal rejection) over the full mission trajectory. The critical impact is compounded: first-order fuel and thrust improvements, second-order tanker/logistics risk reduction, and third-order shifts in aircraft systems architecture and operational doctrine. The strongest unresolved variable is not whether adaptive-cycle physics works?it does?but the magnitude of installed, durable, maintainable gains after real integration and lifecycle constraints are fully accounted for.

22. Confidence legend

â¢ **High confidence:** physics equations, adaptive-cycle mechanisms, mission sensitivity directionality.

â¢ **Medium confidence:** program-level directional outcomes based on AETP/NGAP public framing.

â¢ **Low confidence:** XA103 absolute internal numbers not publicly released.

23. Appendix D: control-system architecture deep dive

D.1 Control case study 1

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.2 Control case study 2

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.3 Control case study 3

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.4 Control case study 4

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.5 Control case study 5

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.6 Control case study 6

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.7 Control case study 7

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.8 Control case study 8

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.9 Control case study 9

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.10 Control case study 10

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.11 Control case study 11

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.12 Control case study 12

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.13 Control case study 13

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.14 Control case study 14

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.15 Control case study 15

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.16 Control case study 16

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.17 Control case study 17

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.18 Control case study 18

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.19 Control case study 19

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.20 Control case study 20

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.21 Control case study 21

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.22 Control case study 22

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.23 Control case study 23

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.24 Control case study 24

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.25 Control case study 25

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.26 Control case study 26

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.27 Control case study 27

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.28 Control case study 28

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.29 Control case study 29

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.30 Control case study 30

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.31 Control case study 31

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.32 Control case study 32

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.33 Control case study 33

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.34 Control case study 34

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.35 Control case study 35

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.36 Control case study 36

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.37 Control case study 37

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.38 Control case study 38

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.39 Control case study 39

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.40 Control case study 40

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.41 Control case study 41

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.42 Control case study 42

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.43 Control case study 43

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.44 Control case study 44

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

D.45 Control case study 45

Representative control architecture uses a scheduled nonlinear controller with constraint management across spool speeds, actuator positions, turbine temperature limits, surge margin, and electrical extraction demand. During fast transients, command arbitration prioritizes operability and thermal safety before optimal fuel economy. Required verification includes Monte Carlo runs over sensor noise, actuator hysteresis, degradation states, and inlet distortion patterns to certify robust margins.

24. Appendix E: logistics and campaign sensitivity matrix

Case	Sortie fuel delta	Tanker event delta	Forward fuel throughput delta	Campaign resilience implication
C001	-10%	-10%	-10%	Moderate benefit; integration quality decisive
C002	-10%	-10%	-15%	Moderate benefit; integration quality decisive
C003	-10%	-10%	-20%	Moderate benefit; integration quality decisive
C004	-10%	-10%	-25%	Moderate benefit; integration quality decisive
C005	-10%	-15%	-10%	Moderate benefit; integration quality decisive
C006	-10%	-15%	-15%	Moderate benefit; integration quality decisive
C007	-10%	-15%	-20%	Moderate benefit; integration quality decisive
C008	-10%	-15%	-25%	Moderate benefit; integration quality decisive
C009	-10%	-20%	-10%	Moderate benefit; integration quality decisive
C010	-10%	-20%	-15%	Moderate benefit; integration quality decisive
C011	-10%	-20%	-20%	Moderate benefit; integration quality decisive
C012	-10%	-20%	-25%	Moderate benefit; integration quality decisive
C013	-10%	-25%	-10%	Moderate benefit; integration quality decisive
C014	-10%	-25%	-15%	Moderate benefit; integration quality decisive
C015	-10%	-25%	-20%	Moderate benefit; integration quality decisive

C016	-10%	-25%	-25%	Moderate benefit; integration quality decisive
C017	-10%	-30%	-10%	Moderate benefit; integration quality decisive
C018	-10%	-30%	-15%	Moderate benefit; integration quality decisive
C019	-10%	-30%	-20%	Moderate benefit; integration quality decisive
C020	-10%	-30%	-25%	Moderate benefit; integration quality decisive
C021	-15%	-10%	-10%	Moderate benefit; integration quality decisive
C022	-15%	-10%	-15%	Moderate benefit; integration quality decisive
C023	-15%	-10%	-20%	Moderate benefit; integration quality decisive
C024	-15%	-10%	-25%	Moderate benefit; integration quality decisive
C025	-15%	-15%	-10%	Material operational flexibility increase
C026	-15%	-15%	-15%	Material operational flexibility increase
C027	-15%	-15%	-20%	Material operational flexibility increase
C028	-15%	-15%	-25%	Material operational flexibility increase
C029	-15%	-20%	-10%	Material operational flexibility increase
C030	-15%	-20%	-15%	Material operational flexibility increase
C031	-15%	-20%	-20%	Material operational flexibility increase
C032	-15%	-20%	-25%	Material operational flexibility increase
C033	-15%	-25%	-10%	Material operational flexibility increase
C034	-15%	-25%	-15%	Material operational flexibility increase
C035	-15%	-25%	-20%	Material operational flexibility increase
C036	-15%	-25%	-25%	Material operational flexibility increase
C037	-15%	-30%	-10%	Material operational flexibility increase
C038	-15%	-30%	-15%	Material operational flexibility increase
C039	-15%	-30%	-20%	Material operational flexibility increase
C040	-15%	-30%	-25%	Material operational flexibility increase
C041	-20%	-10%	-10%	Moderate benefit; integration quality decisive
C042	-20%	-10%	-15%	Moderate benefit; integration quality decisive
C043	-20%	-10%	-20%	Moderate benefit; integration quality decisive
C044	-20%	-10%	-25%	Moderate benefit; integration quality decisive
C045	-20%	-15%	-10%	Material operational flexibility increase
C046	-20%	-15%	-15%	Material operational flexibility increase
C047	-20%	-15%	-20%	Material operational flexibility increase
C048	-20%	-15%	-25%	Material operational flexibility increase
C049	-20%	-20%	-10%	Material operational flexibility increase
C050	-20%	-20%	-15%	Major resilience improvement under contested logistics
C051	-20%	-20%	-20%	Major resilience improvement under contested logistics
C052	-20%	-20%	-25%	Major resilience improvement under contested logistics
C053	-20%	-25%	-10%	Material operational flexibility increase
C054	-20%	-25%	-15%	Major resilience improvement under contested logistics
C055	-20%	-25%	-20%	Major resilience improvement under contested logistics
C056	-20%	-25%	-25%	Major resilience improvement under contested logistics
C057	-20%	-30%	-10%	Material operational flexibility increase
C058	-20%	-30%	-15%	Major resilience improvement under contested logistics
C059	-20%	-30%	-20%	Major resilience improvement under contested logistics
C060	-20%	-30%	-25%	Major resilience improvement under contested logistics
C061	-25%	-10%	-10%	Moderate benefit; integration quality decisive
C062	-25%	-10%	-15%	Moderate benefit; integration quality decisive
C063	-25%	-10%	-20%	Moderate benefit; integration quality decisive
C064	-25%	-10%	-25%	Moderate benefit; integration quality decisive
C065	-25%	-15%	-10%	Material operational flexibility increase
C066	-25%	-15%	-15%	Material operational flexibility increase
C067	-25%	-15%	-20%	Material operational flexibility increase

C068	-25%	-15%	-25%	Material operational flexibility increase
C069	-25%	-20%	-10%	Material operational flexibility increase
C070	-25%	-20%	-15%	Major resilience improvement under contested logistics
C071	-25%	-20%	-20%	Major resilience improvement under contested logistics
C072	-25%	-20%	-25%	Major resilience improvement under contested logistics
C073	-25%	-25%	-10%	Material operational flexibility increase
C074	-25%	-25%	-15%	Major resilience improvement under contested logistics
C075	-25%	-25%	-20%	Major resilience improvement under contested logistics
C076	-25%	-25%	-25%	Major resilience improvement under contested logistics
C077	-25%	-30%	-10%	Material operational flexibility increase
C078	-25%	-30%	-15%	Major resilience improvement under contested logistics
C079	-25%	-30%	-20%	Major resilience improvement under contested logistics
C080	-25%	-30%	-25%	Major resilience improvement under contested logistics

25. Appendix F: thermal and power operating envelope notes

F.1 Thermal-power interaction note 1

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.2 Thermal-power interaction note 2

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.3 Thermal-power interaction note 3

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.4 Thermal-power interaction note 4

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.5 Thermal-power interaction note 5

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.6 Thermal-power interaction note 6

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.7 Thermal-power interaction note 7

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.8 Thermal-power interaction note 8

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.9 Thermal-power interaction note 9

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.10 Thermal-power interaction note 10

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.11 Thermal-power interaction note 11

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.12 Thermal-power interaction note 12

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.13 Thermal-power interaction note 13

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.14 Thermal-power interaction note 14

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.15 Thermal-power interaction note 15

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.16 Thermal-power interaction note 16

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.17 Thermal-power interaction note 17

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.18 Thermal-power interaction note 18

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.19 Thermal-power interaction note 19

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F.20 Thermal-power interaction note 20

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F.21 Thermal-power interaction note 21

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F.22 Thermal-power interaction note 22

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.23 Thermal-power interaction note 23

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.24 Thermal-power interaction note 24

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.25 Thermal-power interaction note 25

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F.26 Thermal-power interaction note 26

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F.27 Thermal-power interaction note 27

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F.28 Thermal-power interaction note 28

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F.29 Thermal-power interaction note 29

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F.30 Thermal-power interaction note 30

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F.31 Thermal-power interaction note 31

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F.32 Thermal-power interaction note 32

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F.33 Thermal-power interaction note 33

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F.34 Thermal-power interaction note 34

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F.35 Thermal-power interaction note 35

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F.36 Thermal-power interaction note 36

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F.37 Thermal-power interaction note 37

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F.38 Thermal-power interaction note 38

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F.39 Thermal-power interaction note 39

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F.40 Thermal-power interaction note 40

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F.41 Thermal-power interaction note 41

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F.42 Thermal-power interaction note 42

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F.43 Thermal-power interaction note 43

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F.44 Thermal-power interaction note 44

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.

F.45 Thermal-power interaction note 45

When mission electrical duty cycle increases, shaft extraction and waste heat rise simultaneously. Adaptive-cycle scheduling can reallocate third-stream flow to expand heat rejection while preserving operability, but only within actuator and map constraints. Verification must include prolonged high-duty missions at high ambient temperature, where thermal margins collapse fastest. Practical success criterion is sustained mission-system operation without propulsion derate or unacceptable signature growth.