Five-Link Rear Suspension for F1

A two-stage agentic AI study with the Vehicle Dynamics Library

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Outline

1. Objective of study
2. 5 link topology
3. Agentic AI workflow
4. Analysis
5. Conclusion (Agentic workflow in Modelon Impact)

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Objective

How much does suspension topology limit an F1 team's ability to retune the rear K&C profile between very different circuits?

The study

- **Stage 1:** compare the design windows of a **five-link** rear and a **double-wishbone** at F1 geometry
- **Stage 2:** check each window against K&C targets for **Monaco** and **Suzuka**

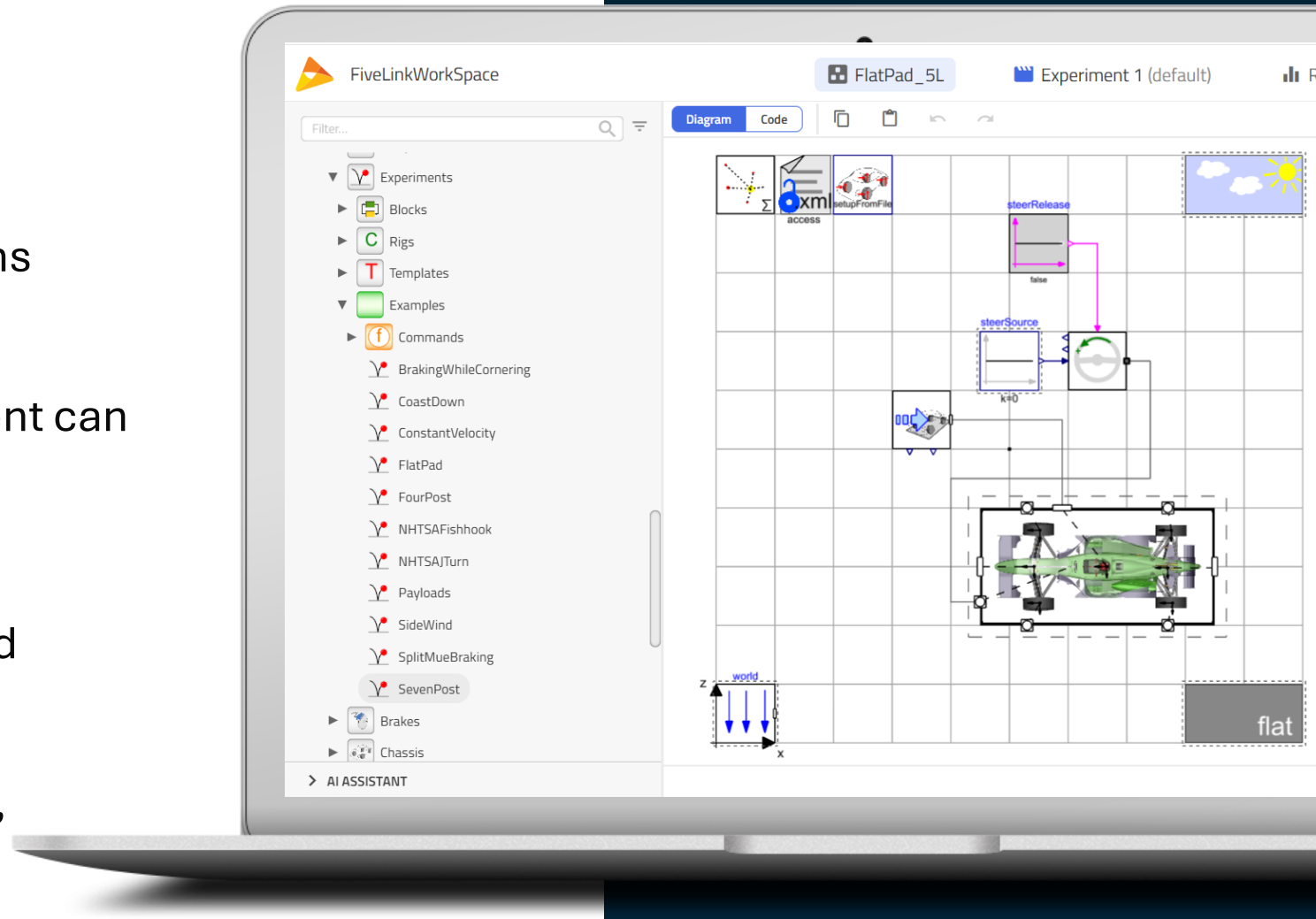
The agent's job

- VDL ships no five-link rear, so the agent **built one from library primitives**, wired the rig, ran the sweeps and made the plots
- **Hours of work** instead of the days a library-experienced engineer would need

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Modelon Impact

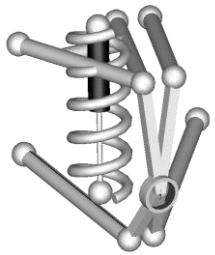
- **Cloud-based** simulation platform
- Compiles and simulates **Modelica**, runs experiments, stores results
- **API** exposes every operation, so an agent can drive it
- **Versioned IDs** for results, FMUs and experiments: any run can be referenced without re-running it
- Familiar formats throughout: Modelica, Python, JSON, Markdown

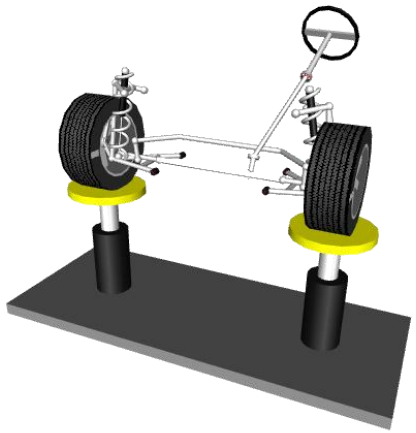


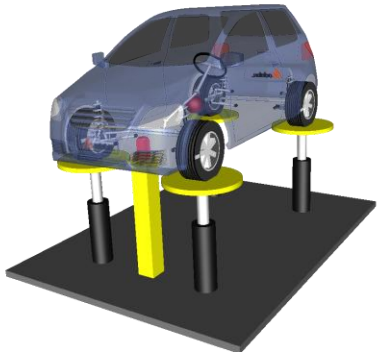
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Validated Physics –Vehicle Dynamics Library

The library is the contract: each validated component carries its physics, so the agent derives **nothing in-session**









Why it matters for this study
Components are replaceable and composable: the agent can swap a joint, redeclare a chassis or extend an experiment without touching equations. **A five-link rear is not in VDL, but every primitive it needs is.**

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Building the 5-link topology

Two topologies, same rig

Double-wishbone

2 A-arms + tie-rod

3 ball joints on the upright; carrier rotates about the axis through the outer A-arm pickups

Five-link

5 binary links

Each A-arm split into two links, tie-rod kept. 5 upright and 5 chassis pickups, each placed individually

What the agent did

1. **Component search:** found suitable elastic link variants, proposed a composition
2. **Interface check:** walked the Linkages.Independent contract, resolved mismatches during assembly
3. **Rig configuration:** adapted similar library experiments, ran a rigid-limit smoke test
4. **Sweep execution:** Latin-hypercube cases via the Impact experiment API, post-processed to K&C metrics
5. **Cross-check:** flagged and dropped degenerate-geometry cases, logged why

No new physics: FiveLinkRear composes existing VDL linkage models and meets the Linkages.Independent interface.

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Agent based workflow

MCP

Model Context Protocol, open JSON-RPC standard

- **~40 typed tools**: orientation, library, model read/write, compile, run, results, DoE, quality
- Every model change is a **typed tool call**, not a free-text edit
- Physical claims trace back to **validated components**

Knowledge

Markdown books layered by lifetime

- Schemas, **methods**, application **playbooks** (A1: vehicle dynamics), physics references
- **Workspace findings** and open hypotheses per project
- Findings are **promoted upward** with provenance, so the next session starts ahead

Guardrails

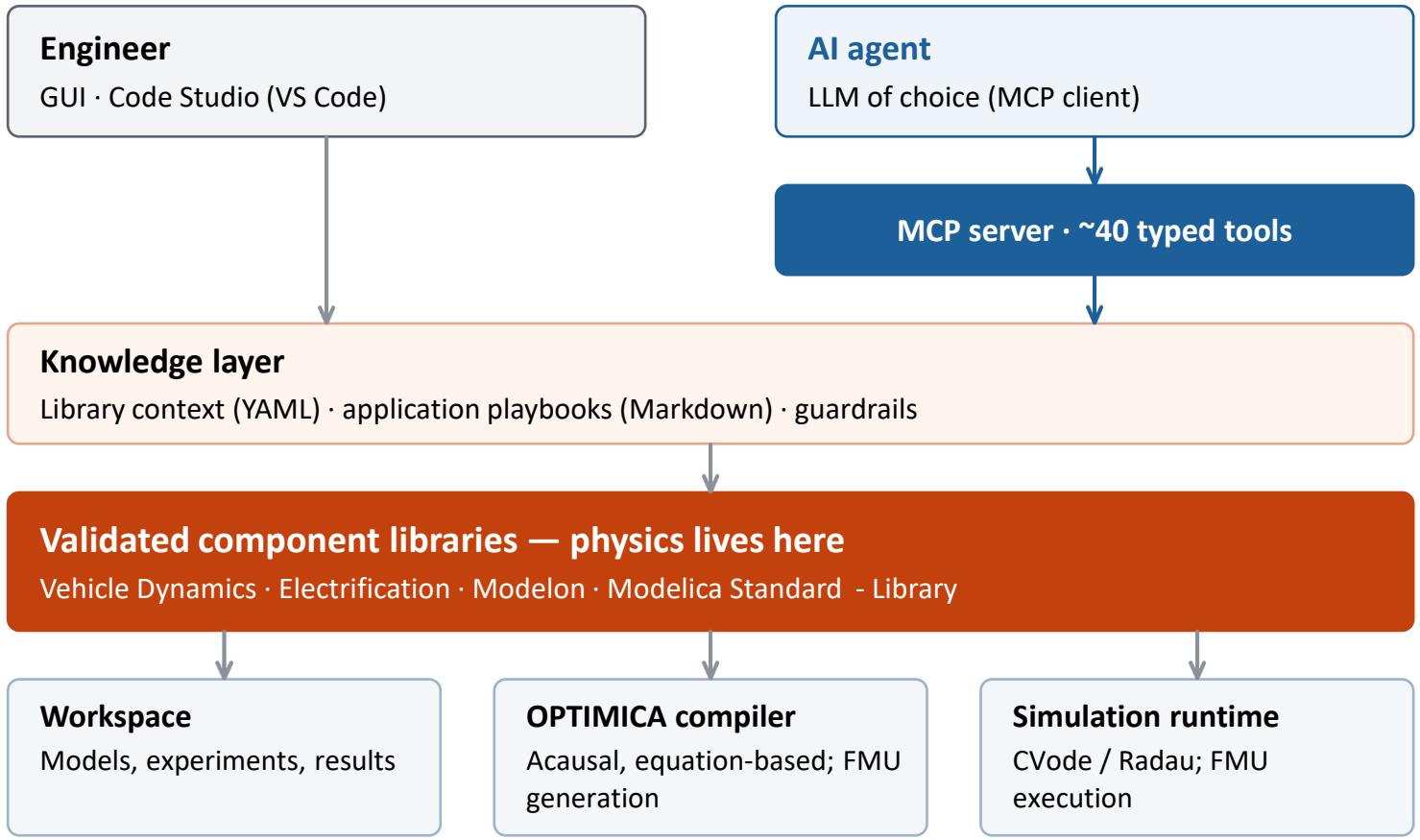
Three checks, regardless of domain

- **Approval gates**: engineer accepts the scope and the analysis
- **Verification tags**: observed, confirmed, verified
- **Provenance**: no number in a report without the run that produced it

The LLM plans, interprets and writes. It is one **replaceable component**; the architecture around it is what makes the output trustworthy.

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Architecture: the agent on top, physics underneath



Engineer and agent share the same Modelon Impact platform services

Every model change is a typed tool call — logged and attributable

Domain knowledge is plain text that experts can write and review

The library carries the physics; the agent selects and composes

Trajectories stay server-side; only KPI scalars enter the LLM context

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MCP turns the platform into typed tools

Model Context Protocol — an open JSON-RPC standard for exposing typed tools to an LLM agent.

- The server wraps the Modelon Impact API as ~40 tools, one per logical operation
- Groups: orientation, library access, model read/write, compile & run, results, DoE, diagram, quality
- Every call returns structured JSON; the whole session is logged
- Building, editing and debugging models all go through the same typed calls

Tool	Returns
get_workspace_libraries	Loaded libraries and versions
list_project_models	Model classes in the project
read_model	Full Modelica source of a model
write_model	Write or overwrite Modelica source
compile_model	Compile to FMU; log and status
run_experiment	Launch dynamic simulation; return ID
get_scalar_results	Named scalar KPIs (JSON)
get_case_results	Time-series trajectories
get_component_interface	Parameters, ports, type info

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A knowledge base layered by lifetime

Schemas	Bill-of-materials format, KPI specification, failure taxonomy
Methods M1–M5	Physics-agnostic procedures: sensitivity, DoE, sweeps, Pareto, reporting
Applications A1–A4	Domain playbooks; only one loads — A1 Vehicle Dynamics
Physics P1–P4	First-principles references the agent can cite
Workspace	Findings, open hypotheses, model and simulation status for this project
User preferences	Per-engineer choices the agent applies by default

Organised by **lifetime**: a finding moves up a layer without dragging session noise with it. A Navigator file is read first.

Promoted from this study

5 Link Assembly template—*Confirmed*
K&C Metric Pipeline —*Confirmed*
Sweep Design with cross check rules - *Confirmed*
Circuit Target Rubric —*Observed*

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Three guardrails, enforced as tools

1 Approval Gates

Structured artifacts the agent must produce, and the engineer must accept before the next phase. (target K&C window and topology coverage comparison)

2 Verification tagging

Every knowledge-base entry carries a provenance tag: *observed*, *confirmed* or *verified* — what was checked vs. assumed.

3 Provenance enforcement

An MCP tool blocks any report containing a quantitative claim not cited to the experiment that produced it.

All three are **enforced through tool calls**, so execution stops until the condition is met. They apply regardless of domain.

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Analysis sweep of 500 designs

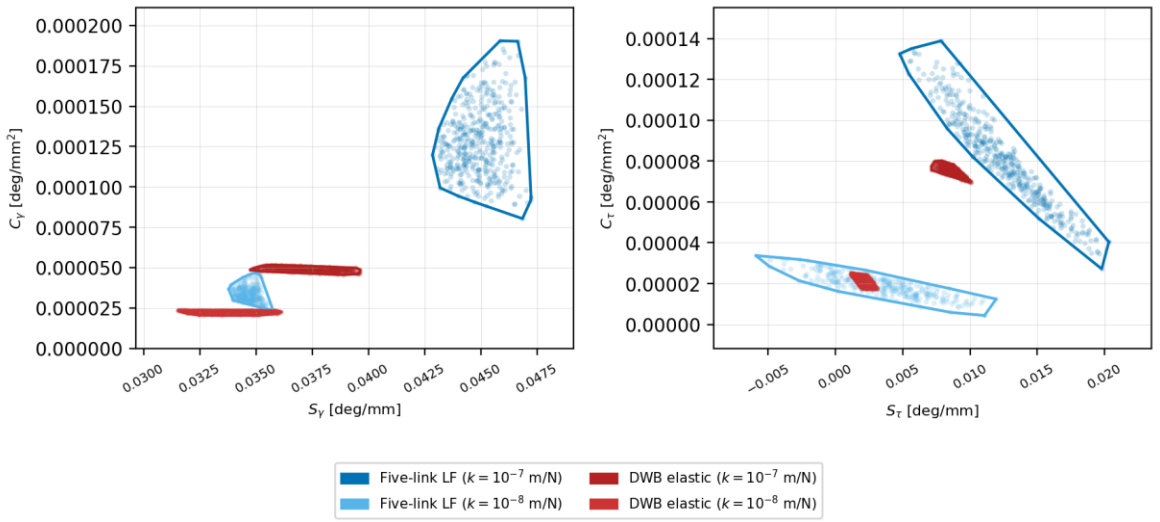
Choosing the right test rig

- VDL virtual **K&C rig**, rear axle, prescribed wheel-pad displacement
- Same rig for both topologies; 12 kg wheel carrier

Latin hypercube expansion

- **500 cases** per topology over pickup positions and link stiffness
- Each case: **±50 mm** wheel travel and up to **4 kN** lateral force
- Two link stiffnesses: **10^7 N/m** (compliant), **10^8 N/m** (stiff)

Design windows at zero load



Left: camber curvature Cγ vs slope Sγ. Right: toe curvature Cτ vs slope Sτ. **Blue five-link, red double-wishbone**; dark shades compliant links.

Stage 1 result: double-wishbone clusters at $S_\gamma \approx 0.030–0.035$ deg/mm with near-zero curvature. **Five-link reaches 0.045–0.048 deg/mm** with compliant links and spans a much wider curvature range.

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Circuit comparison

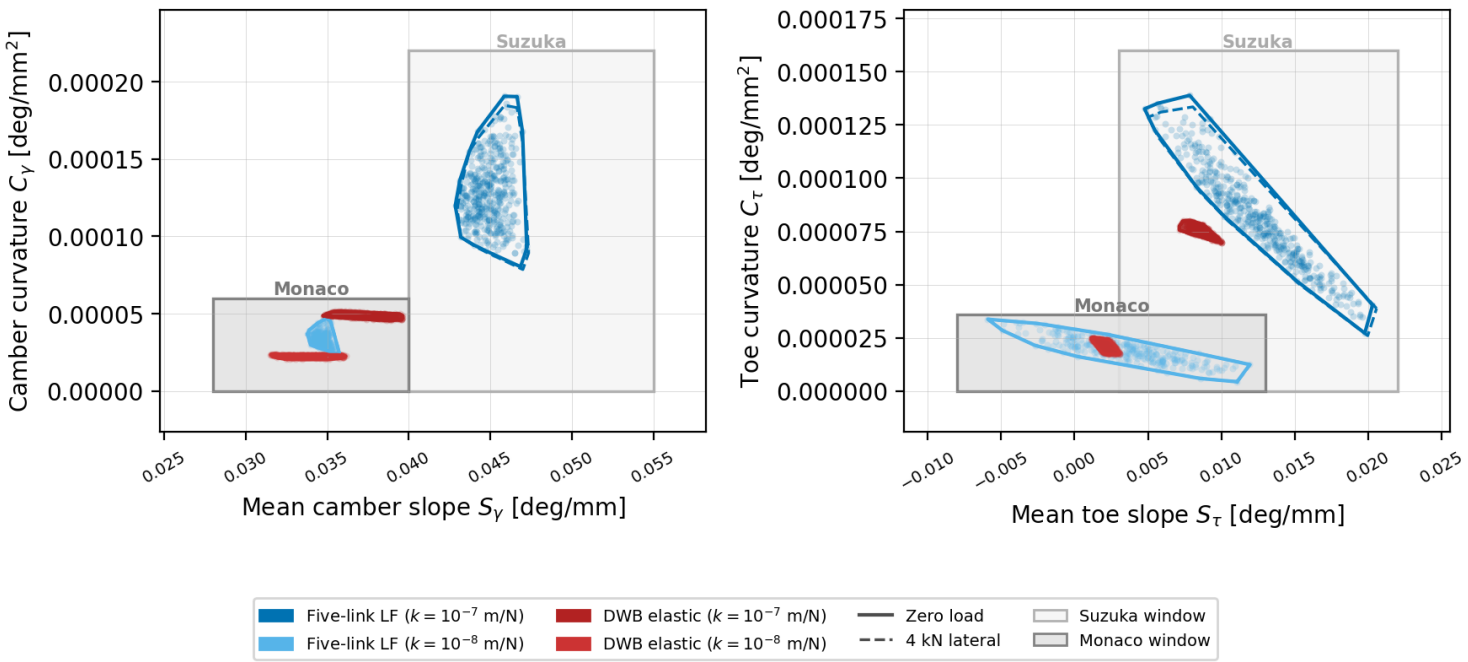
Two circuits at opposite ends of the calendar set different K&C targets for the rear axle

	Monaco	Suzuka
Circuit	Street, 3.34 km, ~150 km/h average	Permanent, 5.81 km, ~225 km/h average
Rear travel, body roll	Wide travel, large roll	Narrow, aero-pinned, small roll
Aero load, kerbs	Low aero, kerbs everywhere	4–5 g sustained, targeted kerbs
Camber slope S_γ	Moderate	Higher
Camber curvature C_γ	Small	Tolerable
Toe slope S_τ	Small	Small
Toe curvature C_τ	Small	Tolerable
Link compliance	Relatively soft	Stiff (near-rigid)

Shaded rows: target K&C window. Targets are reasoned from circuit character, not measured vehicle data, and are illustrative. Singapore and Baku resemble Monaco; Silverstone and Spa resemble Suzuka.

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Results



Circuit target coverage

	Monaco	Suzuka
Double-wishbone	✓ camber only	✗ not reached
Five-link	✓ stiff links	✓ compliant links

One five-link model spans both targets: stiff links (10^8 N/m) reach Monaco, compliant links (10^7 N/m) reach Suzuka. Double-wishbone reaches only the Monaco camber window, and its compliant variant misses the Monaco toe target.

Coverage is conditional on the illustrative, reasoning-derived target windows; shifting the window boundaries could change which subsets fall inside. The structural difference between the topologies is the robust result.

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Conclusion on Study

1

Five-link opens a wider K&C design window

It covers substantially more of the camber and toe slope-curvature space than double-wishbone, at every lateral load tested.

2

One chassis can span opposite circuits

Under the illustrative targets, five-link reaches both Monaco and Suzuka; double-wishbone reaches only Monaco.

3

Compliance is the per-event lever

Pickups are fixed at design time; a kit of calibrated link bushings can be swapped between events in a few hours of wheel-corner work.

4

Next: ground the targets in data

Target windows from track data, tyre models and lap-time sensitivity, applied across the full calendar, would make the result quantitative.

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Conclusion on methodology

Where the agent helps

- **Surveys** in one session a library section that takes a day by hand
- **Debugs** vague compile errors and BLT diagnostics
- **Writes** sweep, post-processing and plotting scripts
- **Explains** legacy components with thin documentation

Where it adds work

- **More code to review**: output grows faster than review capacity
- **Little gain** on routine sweeps of existing templates

Engineer stays in charge

- The engineer set the claim and the circuit targets
- Two mandatory **approval gates**: scope and analysis
- **Four findings** promoted to the playbook for the next study

Best fit: a **well-defined question with unfamiliar assembly work**. The same architecture already runs on thermal, powertrain, HVAC and data-centre libraries.

Agentic capabilities integrated into Modelon Impact AI Assistant

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Accurate Simulations. Better Decisions.

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