Non-Contact EM Turbulence Sensor

Technical Due Diligence Review

Investor assessment of physical realizability, signal-to-noise ratio, and beachhead viability by fluid class

Executive Verdict

Proceed only on the molten-metal beachhead. The underlying motional-induction physics is sound, and liquid-metal signal magnitudes are compatible with rugged fluxgate instrumentation. Seawater piping, blood flow, and most industrial electrolytes do not close as standalone non-contact turbulence products under ordinary sensor and noise constraints.

Prepared by InTelluric | Technical Due Diligence Review | June 2026

Executive Scoring Risk Summary

The proposed non-contact electromagnetic turbulence characterization instrument is physically real in a narrow operating envelope, but the viable envelope is not the broad fluid-class set implied by the raw concept. The correct investment posture is a molten-metal turbulence and flow-structure diagnostic first, with electrolyte work held as a post-milestone option and seawater/blood product lines terminated or reframed as research-only physics demonstrations.

Criterion	Risk	Kill Factor	Repair / Diligence Action
Physical Realizability	LOW for liquid metals; HIGH elsewhere	Rm collapses by 5-8 orders of magnitude outside high-conductivity fluids.	State the operating envelope explicitly: sigma >= 1e5 S/m, L ~0.1-1 m, u ~0.1-2 m/s, turbulence intensity >=3-5%.
Signal Detectability	LOW-MED	Industrial 50/60 Hz line tones are microtesla-scale and exceed raw signals.	Require AC excitation, lock-in detection, gradiometry, and plant-noise rejection before claiming deployment readiness.
Inversion to Turbulence Metrics	HIGH	The instrument measures fluctuating B-field, not Reynolds stress directly.	Make Reynolds-stress inversion a Phase I objective. Demonstrate recovery of a known turbulence proxy in liquid metal before quantitative claims.
Prior Art / IP Space	LOW-MED	CIFT, ECFM, magmeters, and contact EM turbulence probes occupy adjacent terrain.	Claim the white space narrowly: external EM fluctuation sensing for turbulence/flow-structure diagnostics in opaque conductive flows.
Market Focus	MED	The general flow-meter market is large, but this is not a mean-flow meter.	Position around high-value opaque/hot/hostile flows: steel/aluminum casting, sodium/lead coolant loops, fusion blankets.
Verdict	GO / CONDITIONAL / NO-GO by fluid class	Single-product broad-fluid narrative breaks on SNR.	GO molten metals; CONDITIONAL electrolytes after molten-metal milestone; NO-GO seawater pipe and blood standalone products.

Bottom line: fund a Stage 1 liquid-metal demonstrator. Do not fund a generalized non-contact turbulence sensor until the magnetic-field inversion and industrial noise-rejection chain are proven under molten-metal conditions.

Key Findings

- Signal strength is governed by magnetic Reynolds number, Rm = mu0 sigma u L. Liquid metals sit near Rm ~0.1-1; seawater, electrolytes, and blood fall orders of magnitude lower under pipe-scale conditions.
- The measurable quantity is the induced magnetic-field fluctuation. Reynolds stress is not observed directly; it must be inferred through an inverse model that may be non-unique.
- Liquid-metal experiments and CIFT literature already demonstrate externally measurable induced fields. Reported CIFT-scale signals around 100 nT under applied excitation are compatible with industrial fluxgate sensors.
- Industrial line noise is a deployment problem, not an afterthought. Even viable liquid-metal signals require lock-in, gradiometric rejection, and deliberate excitation-field design.
- The addressable market is not the whole flow-meter market. The natural beachhead is opaque, hot, hostile, conductive flow where optical methods fail and contact probes are impractical.
- Biomedical and seawater-pipe claims should be removed from the product roadmap unless the story is explicitly downgraded to SQUID/shielded-room research instrumentation.

Signal Level Estimation

The diligence calculation is dominated by one parameter: Rm = mu0 sigma u L. The induced magnetic field scales with Rm times the bias or excitation field; the turbulent component scales further with the velocity fluctuation fraction and the turbulence spectrum. For investor screening, this converts the concept from a general fluid sensor into a high-conductivity-fluid sensor.

Fluid	Conductivity sigma	Representative u / L	Rm	Diligence implication
Molten aluminum	3.5e6 S/m	u ~0.5 m/s; L ~0.5 m	~1.1	Viable. Signal is in fluxgate range.
Molten steel	7e5 S/m	u ~0.1-1 m/s; L ~1 m	~0.1-0.9	Viable to borderline-viable depending on geometry and excitation.
Industrial electrolyte	10-100 S/m	u ~2 m/s; L ~0.5 m	~6e-5	Marginal. Requires excitation, shielding/noise rejection, and long integration.
Seawater	~4 S/m	u ~2 m/s; L ~1 m	~1e-5	No-go at pipe scale for ordinary instrumentation.
Blood	~0.7 S/m	u ~1 m/s; L ~0.02 m	~2e-8	No-go outside SQUID/shielded-room biomagnetism context.

Expected Fluctuating Magnetic Field

Using Earth-field passive bias as a first-pass lower-complexity case, liquid metals reach the ~0.1-1 uT class, while electrolytes, seawater, and blood fall into pT-to-fT territory. An applied excitation field near the CIFT regime (~0.5-1 mT) improves signal magnitude and enables phase-sensitive detection, but it does not rescue low-conductivity fluids into a normal industrial product by itself.

Fluid class	Expected b-prime	Detector class	Verdict
Molten aluminum / steel / sodium	~0.1-1 uT; liquid-metal measurements anchor the range	Fluxgate or induction-coil array	GO
Concentrated electrolyte	~60-100 pT passive; higher with excitation	Best fluxgate or SQUID; shielding likely	CONDITIONAL
Seawater piping	~10 pT pipe-scale	SQUID / very quiet environment	NO-GO as product
Blood flow	~10-20 fT external magnetic signature	SQUID + magnetic shielding	NO-GO as product

System Architecture Audit

The proposed instrument should be audited as a measurement chain. Each arrow must be supported by a measurement, published basis, or go/no-go threshold. The strongest version of the concept does not claim that Maxwell stress is Reynolds stress; it claims that externally measured magnetic-field fluctuations can be inverted into useful turbulence or flow-structure information under a constrained fluid class.

Stage	Function	Risk	Known basis	Measurement required
1. Excitation / bias field	Provide stable field against which conductive flow produces induced field.	LOW	CIFT and magmeter practice; controlled coils and lock-in drive are established.	Coil field amplitude, stability, phase reference, and rejection of direct pickup.
2. Motional induction in turbulent flow	Convert velocity fluctuations in conductive fluid into fluctuating magnetic field.	LOW for metals; HIGH for low-conductivity fluids	MHD and liquid-metal induction experiments; Rm scaling.	b-field spectrum vs. known flow state, Rm, and turbulence intensity.
3. Sensor array	Measure external magnetic-field perturbations without contact with fluid.	LOW-MED	Fluxgates/induction coils used in CIFT and liquid-metal diagnostics.	Noise floor, bandwidth, thermal stability, standoff sensitivity, sensor calibration.
4. Industrial noise rejection	Recover nT-scale or sub-nT signal under uT-scale line tones and plant noise.	MED-HIGH	Lock-in, gradiometry, notch filtering, reference sensors.	Demonstrate >=60 dB rejection while preserving injected/fluctuating signal.
5. Inverse reconstruction	Map measured magnetic fluctuations to turbulence statistics or flow-structure features.	HIGH	CIFT solves a related mean-flow inverse problem but suppresses small vortices.	Recover known large-scale modes and at least one turbulence proxy in a validation loop.

Stage	Function	Risk	Known basis	Measurement required
6. Industrial package	Operate near hot/opaque/hostile flows with stable calibration.	MED	ECFM/CIFT hardware analogs exist, but turbulence-specific package is not mature.	Thermal isolation, sensor standoff, calibration drift, maintenance model.

Architecture audit finding

All technical risk concentrates in two places: (1) plant-noise rejection under real industrial EM conditions, and (2) the inverse reconstruction from fluctuating B-field to quantitative turbulence statistics. A Phase I that only detects magnetic fluctuations is insufficient; it must show the beginning of a stable inversion against a known turbulent reference flow.

Existing Technology and Prior Art Position

Magnetic flowmeters are not direct competitors for turbulence measurement. They use Faraday induction to measure mean volumetric flow and their installation guidance typically attempts to suppress turbulence before measurement. That helps position the proposed instrument away from commodity flow metering and toward diagnostics for flows where contact and optical methods fail.

The closest technical prior art is Contactless Inductive Flow Tomography (CIFT), especially HZDR work on liquid-metal flow reconstruction. CIFT proves that external induced-field measurements can reconstruct flow features in liquid metals, but it also exposes the central limitation: the inverse problem is regularized for mean or large-scale flow and is not naturally a small-vortex turbulence microscope. That limitation should be treated as the starting point for the invention, not ignored.

Technology / prior art	What it proves	What it does not prove	Implication
Magmeters	Conductive mean-flow metering is mature and large-market.	Non-contact turbulence or Reynolds-stress measurement.	Do not compete as a mean-flow meter.
CIFT / HZDR	External induced-field sensing can reconstruct liquid-metal flow fields.	Quantitative small-scale turbulence or Reynolds stress from field fluctuations.	Best technical beachhead and partner/licensing target.
ECFM in sodium / lead-bismuth loops	Non-contact EM sensors survive high-temperature liquid-metal service.	Turbulence tensor inversion.	Validates industrial environment and package analogs.
VKS / Madison dynamo experiments	Turbulent induced-field fluctuations scale with Rm and can be large in liquid metals.	Product-ready flow diagnostics.	Provides physics anchor for fluctuation measurement.
Contact EM turbulence probes / patents	Reynolds-stress EM measurement was explored with contact probes.	External non-contact reconstruction.	Non-contact field-based claim space appears narrower but real.

Noise Floor and SNR

The viability barrier is not merely sensor sensitivity. In a plant, the target signal sits inside a magnetic environment dominated by 50/60 Hz power-line fields and harmonics. Microtesla-scale interference can exceed the raw target signal even when the intrinsic fluxgate floor is pT/sqrt(Hz). Therefore the device architecture must be excitation-referenced rather than passive wherever possible.

Illustrative viable case: if the recoverable liquid-metal fluctuation signal is ~100 nT and the fluxgate noise is ~5 pT/sqrt(Hz), the integrated sensor floor over a 1 Hz-1 kHz band is about 0.16 nT before line-tone rejection. After lock-in/gradiometric rejection, raw SNR can exceed 50 dB. The same arithmetic fails for electrolytes without applied field and fails completely for blood outside biomagnetic laboratory conditions.

Signal class	Approx. signal	Intrinsic sensor feasibility	Industrial noise risk	Diligence decision
Molten metal	100 nT-1 uT	Strong with fluxgate	Manageable with lock-in/gradiometry	Proceed to demo
Electrolyte	~60-100 pT passive	Marginal	Severe	Only after metal milestone
Seawater pipe	~10 pT	Technically possible only in quiet setups	Severe	No product

Signal class	Approx. signal	Intrinsic sensor feasibility	Industrial noise risk	Diligence decision
Blood	~10-20 fT	SQUID-class	Motion/biomagnetic confounds dominate	No product

Technical Objective Map

A credible diligence plan must retire the viability chain in order: detectable liquid-metal fluctuation signal, noise rejection, inversion stability, and industrial relevance. The work should not begin with broad-fluid demonstrations.

Objective	Measurement	Pass criterion	Deliverable
Objective 1 - Liquid-metal fluctuation detection	GaInSn or sodium/steel analog loop with applied AC field; external fluxgate or induction-coil array.	Recover fluctuating induced-field spectrum >=1 nT with SNR >=10 after rejection chain.	B-field spectrum vs. Rm, turbulence intensity, and excitation amplitude.
Objective 2 - Noise rejection in hostile EM environment	Inject/reference known signals under controlled 50/60 Hz and harmonic contamination at uT scale.	>=60 dB line-tone rejection without erasing target fluctuation band.	Lock-in/gradiometric noise-rejection validation report.
Objective 3 - Inversion demonstration	Compare external magnetic statistics against known/independent flow state from UDV, CIFT mean-field reconstruction, or controlled geometry.	Recover dominant large-scale flow structure and at least one predeclared turbulence proxy.	Inversion error map and non-uniqueness analysis.
Objective 4 - Beachhead application screen	Map system to steel/aluminum casting or reactor coolant loop requirements.	A named use case has measurable value and an integration path.	Phase II product specification and partner target list.

Recommended Phase I Diligence Plan

Aim 1 (Months 1-2): Bench signal-chain and excitation validation

Build the excitation coil, lock-in reference, gradiometer channel, and sensor array around a non-flowing conductive surrogate first. Measure direct pickup, rejection ratio, sensor drift, bandwidth, and calibration stability. This aim retires instrumentation risk before any fluid-loop complexity is added.

Aim 2 (Months 2-5): Liquid-metal loop fluctuation detection

Use a GaInSn loop or accessible liquid-metal testbed. Drive controlled flow states and recover externally measured magnetic-field fluctuations. The minimum success condition is not qualitative detection; it is a repeatable spectrum with amplitude, phase coherence, and Rm dependence that tracks the imposed flow state.

Aim 3 (Months 5-7): Inversion and non-uniqueness test

Run a known flow configuration with independent reference data. Fit external magnetic measurements to large-scale flow features and predeclared turbulence proxies. Quantify which quantities are recoverable, which are non-unique, and which require additional sensors or excitation geometries.

Aim 4 (Months 7-9): Use-case packaging and Phase II scoping

Translate the surviving sensor architecture into one beachhead product specification: steel caster, aluminum launder, sodium/lead-bismuth coolant loop, or fusion blanket test loop. Produce a bill-of-materials estimate, sensor standoff envelope, thermal isolation concept, calibration protocol, and integration path.

Milestone / Go-No-Go Table

M#	Milestone	Pass condition	No-go condition	Contingency
M1	Instrument chain rejects direct pickup and line-tone contamination.	>=60 dB rejection while preserving reference signal phase and amplitude.	Reference signal cannot be recovered under controlled contamination.	Redesign coil/sensor geometry; add reference sensors; narrow bandwidth.

M#	Milestone	Pass condition	No-go condition	Contingency
M2	Liquid-metal fluctuation spectrum recovered.	>=1 nT fluctuation spectrum with SNR >=10 and repeatable dependence on flow state.	No repeatable signal above sensor/noise floor.	Increase excitation, reduce standoff, change sensor class, or stop.
M3	Inversion recovers predeclared flow feature.	Dominant flow structure or turbulence proxy recovered within predeclared error tolerance.	External field statistics are non-unique or unstable.	Reframe as qualitative flow-structure monitor rather than Reynolds-stress instrument.
M4	Beachhead product specification completed.	One industrial use case has clear integration, measurement value, and buyer/partner target.	No application beats incumbent diagnostics economically.	Switch to licensing / research-instrument strategy.

Failure Mode Map

Failure mode	Detection path	Consequence	Repair / decision
Signal below plant noise	No repeatable target-band signal after lock-in/gradiometry.	Even molten-metal use case becomes lab-only.	Increase excitation/standoff control; if still absent, stop product development.
Direct excitation pickup masquerades as flow signal	Signal persists without flow or does not scale with flow state.	False-positive instrument.	Redesign sensor/coil geometry and subtract reference channel; require flow-off controls.
Inversion non-unique	Different flow states yield indistinguishable external B statistics.	Reynolds-stress claim fails.	Downgrade to flow anomaly / structure monitor; add sensor density or excitation modes.
Thermal/mechanical package drift	Calibration shifts under hot duct/caster environment.	Industrial deployment unreliable.	Move sensors farther from heat, add thermal reference, calibrate in situ.
Electrolyte pilot fails SNR	Representative electrolyte signal remains <3 SNR after excitation and shielding.	Electrolyte branch not fundable.	Terminate electrolyte branch; retain molten-metal roadmap.
Market pulls toward mean-flow metering	Customers compare product to commodity magmeters.	Sales cycle collapses on cost/performance mismatch.	Position as turbulence/flow-structure diagnostic only.

Market and Commercial Position

The flow-meter market is large, but this instrument should not be presented as a replacement for magnetic flowmeters. Commodity magmeters already solve mean conductive flow metering. The valuable gap is turbulence and internal flow-structure measurement in opaque, hot, hostile, or sealed conductive systems where optical, contact, and ultrasonic approaches break down.

Application	Pain point	Fit	Commercial posture
Molten steel / aluminum casting	Flow structure affects defects, inclusions, meniscus stability, and product quality.	Strong	Primary beachhead; CIFT-adjacent but turbulence-focused.
Sodium / lead-bismuth reactor coolant loops	Opaque, hot, radioactive liquid metal; contact instrumentation limited.	Strong but regulated	High-value technical market; partner with labs and reactor developers.
Fusion blankets / liquid-metal test loops	Need flow diagnostics in hostile, opaque blanket channels.	Strong research market	Research-to-industrial bridge.
Concentrated electrolyte reactors	Some conductive closed systems; signal marginal.	Conditional	Pilot only after metal validation.
Seawater piping	Conductivity too low at pipe scale.	Weak	Remove from product thesis.
Blood flow	External magnetic signal in fT range and motion confounds dominate.	Weak	Remove; research-only biomagnetism framing.

Caveats

- Liquid-metal signal magnitudes are anchored to published induced-field and CIFT/dynamo measurements; low-conductivity-fluid estimates are order-of-magnitude extrapolations.
- Passive Earth-field operation is not the recommended primary product architecture. Applied excitation is almost certainly required for robust industrial deployment.
- Industrial noise rejection is the dominant practical risk. A laboratory detection result without plant-noise stress testing does not validate the product.
- Quantitative Reynolds-stress recovery is an inverse-problem claim. Until demonstrated, the safe product claim is turbulence/flow-structure characterization.
- Market estimates vary by source and segmentation. Treat the large flow-meter market as context, not TAM for this device.

Selected Technical Basis

1. Shercliff, J.A. The Theory of Electromagnetic Flow-Measurement. Cambridge University Press, 1962.
2. Stefani, F. and Gerbeth, G. Contactless inductive flow tomography. Measurement Science and Technology. 2000;11:758.
3. Stefani, F., Gundrum, T., and Gerbeth, G. Contactless inductive flow tomography. Physical Review E. 2004;70.
4. Bourgoin / Volk et al. von Karman sodium experimental work on magnetic-field fluctuations and Rm scaling.
5. Spence, Nornberg, and Forest. Madison Dynamo induced-field measurements at high magnetic Reynolds number.
6. Ratajczak / Sieger et al. CIFT sensor implementation and magnetic-field measurement range in liquid-metal applications.
7. Deprez et al. Sensors 2024. Measurements of environmental low-frequency magnetic fields near high-voltage and distribution infrastructure.
8. Representative ECFM programs: ORNL, PNNL FFTF, Argonne/INL/VTR, PFBR/FBTR, and Phenix liquid-metal coolant instrumentation.
9. US 3,964,306 and US 4,028,939: contact electromagnetic Reynolds-stress / drag probe prior art.

Final diligence recommendation

Fund a molten-metal Phase I only. The program should demonstrate a turbulence-correlated external magnetic fluctuation spectrum, industrial noise rejection, and a bounded inversion to flow-structure metrics. If those gates fail, the concept should be downgraded from quantitative turbulence instrumentation to a qualitative flow-anomaly monitor or terminated.