SMP '09 Trondheim

50 Years Rational Theory of Propulsion
Recent Results and Perspectives

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Talking about fifty years of intense research and development off the beaten track

- I shall not tell you anecdotes and jokes,
- but I shall rather talk about the future,
- about the origin and the development of ideas,
- about basic models and underlying 'assumptions',
- usually not explicitly stated in reports and papers,
- but of crucial importance for the success and value of the work reported.
- My paper links up directly with the paper by Neil Bose and you will find many questions he has posed answered by my procedure of unconstrained quasi-steady testing, model and full scale.

Motto of my work

'Immediate plausibility and the agreement with the usual jargon indicate - far from being philosophical virtues **- that not much progress has been achieved or will be achieved.'**
Paul Feyerabend: ***Against*** **[*the dictates of*]** ***method,*** *1965*.

Do not belief anybody, *not even me*, but stick to the Kant's slogan of rationalism:
***Sapere aude*, dare to think yourself**!

- When I wanted to reconstruct ship theory for the difficult problems at hand I did *not* ask naval architects but rather 'architects' of theories.
- The simple reason is that there is no chance to pull yourself out of the morass, as the Germans, following Baron von Münchhausen, do by their braids, or as the Anglo-Saxons do by their bootstraps.

Problems solved

Introduction
Meta-models
Traditional trials
Theory of interactions
Quasi-steady trials
on model scale
on full scale
Ducted propulsors
Conclusions

• My extremely short presentation, as my very short paper, can only draw your attention to solutions of fundamental problems of ship theory in terms of the rational theory of propulsion.

• These problems have not been and cannot possibly be solved in the traditional framework, which has caused them.

• All the details are to be found in various papers and worked examples mostly already to be found on my website.

Meta-model, meta-physics

The basic problems to be solved are *not* physical, *not* hydrodynamical problems, *but* conceptual problems arising in the resolution of conflicts between the parties concerned, typically ship owners and ship yards.
And the essential result of conflict theory is that conflicts can be resolved rationally only by setting up coherent, i. e. axiomatic systems of conventions to be agreed upon by the parties, the players taking part in the game.

Coherent systems of conventions consist

• of basic concepts implicitly, coherently 'defined' by basic sentences, the axioms, and

• of rules formally to *define* further concepts and to *deduce* further sentences,

• the 'theorems', the consequences, which 'have to be' accepted by each of the parties having agreed upon the basics and the rules of the game.

• Such systems, essentially formal languages are not results of ad hoc 'magic tricks' or more or less 'professional fumbling and development over centuries', but can be constructed professionally 'model based'.

Representation spaces

Systems of the type outlined have been set up among others: explicitly since 1980

- for **hull-propeller interactions** permitting the **identification** of all powering performance parameters **on model scale and on full scale**

and based on that work, explicitly since 1998

- for the **evaluation** of traditional steady speed trials **without any reference to ship theory, to model test results and to any other prior information, <u>as it must be</u>.**

SMP '09 Trondheim Schmiechen 5

• The theories developed are essentially normative theories, models unfolding representation spaces, the parameters being the 'coordinates' of the systems considered.

• The 'only' task of hydrodynamicists is to identify the values of parameters defined by axiomatic ship theory.

• The emotional reactions to this statement do not change the situation, but support my argument.

• Identification is essentially a matter of experiments, either physical or computational, and their evaluation.

• These sub-tasks have to be performed professionally. For my taste there are too many traditionally trained naval architects working at model basins.

Craftsmanship

To be specific, the craftsmanship required includes the capabilities

- **to solve ill-conditioned systems of linear equations** by singular value decomposition,
- **to estimate spectra from truncated records** using auto-regressive models,
- **to identify systems in noisy feed-back loops** using correlation with signals independent of the noise,
- and, last but not least, **to use the axiomatic approach.**

SMP '09 Trondheim Schmiechen 6

• All of these techniques, mandatory for successful applications, are described in great detail in papers and lectures to be found on my website.

• More fundamental and serious than the lack of craftsmanship is the lack of phantasy in understanding the problems to be solved and the solutions developed, impossible in the traditional framework, which have caused the problems.

• *To reduce the 'rational approach' to 'systems identification' indicates, that its essence has not been understood.*

• As simplest example I sketch the evaluation of traditional steady trials.

Traditional trials: limited horizons

Due to the very small variability of the data ***the most general performance function that can be identified with confidence*** is a linear function

$$K_P = K_{P0} + K_{PH} J_H .$$

With the ship speed over ground, to be measured by GPS, and the unknown current speed over ground the hull advance ratio is

$$J_H = J_G - J_C .$$

The unknown current velocity may be assumed as polynomial function of time.

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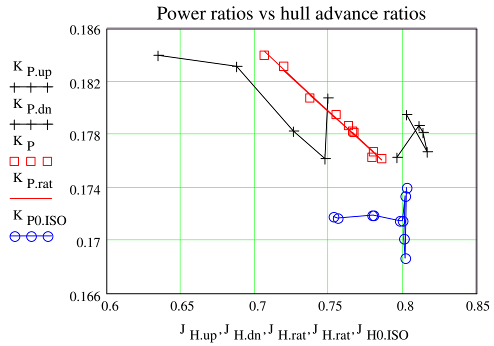
- Based on a half-sentence in my METEOR reports of 1990/91 I have demonstrated that the Japanese ISO CD, later DIS 15016 was not only error prone.
- It is also lacking the transparency urgently requested by ship owners, navies in particular, and lacking the precision necessary for the validation of powering predictions and of computational 'codes'.
- Despite severe reservations of many yards ISO 15016: 2002-06, standardizing the unsatisfactory practice of our grandfathers, has been adopted after consent of most national Standards Groups.

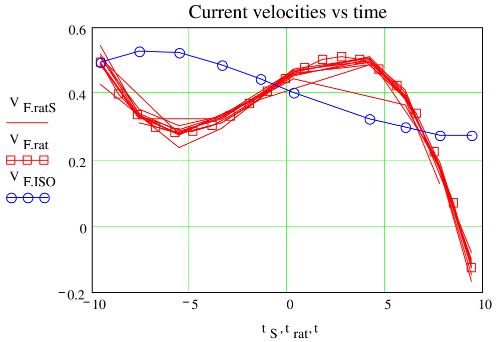
Propeller 'behind': ISO example *1998*



SMP '09 Trondheim Schmiechen 8

- Although I have informed all bodies 'concerned' accordingly in time and told them how to circumvent the problems nobody felt 'concerned'.
- And despite the evident systematic error in the example provided with the standard the latter has been approved again without change in 2008 by most national Standards Groups.
- The 'impossible' power curves in the ISO example are due to systematic mistakes in the determination of the current velocity shown in the next slide.

Current: ISO example *1998*



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• This very simple, but fundamental example clearly shows that the present, very involved practice is based on superfluous assumptions, to put it mildly. But who likes to be told that his deeply rooted beliefs are plain superstition?

• I only mention that the same methodology has been used to determine the performance at no wind and no waves etc etc and for monitoring purposes under service conditions.

• The method proposed has been further developed at HSVA since 1999 and is being used at MARIN in two related recent joint industry projects.

Hull-propeller interactions *1968, 1980*

Not all problems are as simple as the evaluation of speed trials. ***An intuitive rational procedure to arrive professionally, without guess work at axiomatic systems is*** to adopt some simple, adequate, i.e. ***'sufficiently rich'*** *hydromechanical systems model*.

The model adopted here is that of the **equivalent propulsors outside the displacement wakes already proposed by Fresenius in 1924 but hardly exploited.**

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• This is the only rational way to solve the basic problems at hand: to replace hull towing tests and propeller open water tests.

• A formidable practical problem in full scale applications is that the complete analysis requires reliable thrust measurements.

• The following slides do not show the complete theory but only the axioms replacing hull towing tests and propeller open water tests.

Thrust deduction axiom *1990, 1997*

Starting points are the ***momentum balance*** and the model of the ***equivalent propulsor outside the displacement wake***.

The global approximation of the thrust deduction theorem leads directly to the plausible thrust deduction axiom

$$t = t_{TJ}\ \eta_{TJ}$$

with the nominal thrust deduction fraction

$$t_{TJ} = \text{const}$$

and the jet efficiency η_{TJ} of the propeller.

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• In case of advanced hull propeller configurations the hull towing tests provide at best useless data and, most importantly, they cannot be performed on full scale under service conditions.

Wake axioms, local *2002, 2008*

The starting point is the ***energy balance*** …

Correspondingly the 'plausible' wake axioms are

$$w = w_{TJ}\ \eta_{TJ}$$

with the nominal wake fraction

$$w_{TJ} = \text{const}$$

and the further axiom concerning ***the pump efficiency in the range of interest***

$$\eta_{JP} = \max$$

This condition, ***introduced to provide for a robust procedure***, has to be carefully observed (2008).

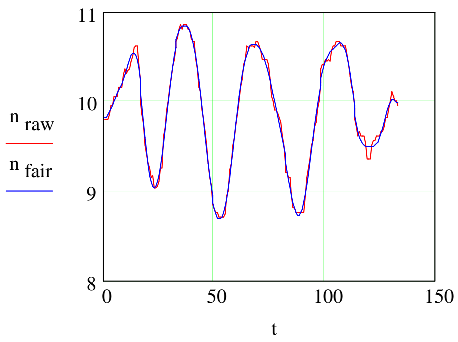
SMP '09 Trondheim Schmiechen 12

• A satisfactory theoretical foundation, as provided in case of the thrust deduction fraction, is still missing, but based on open water test results the plausibility has been demonstrated successfully.

• After the solution of the wake problem all powering performance parameters can be determined in the range of observed hull advance ratios.

• The following slides show raw data recorded during a quasisteady 'model' propulsion test of two minutes duration, as well as the derived speed variation and acceleration.

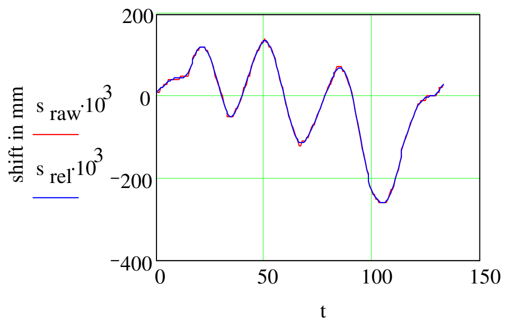
Raw data: rate of revolutions *1987*



SMP '09 Trondheim	Schmiechen 13

- The quasi-steady model test has been performed prior to the full scale METEOR tests to demonstrate the feasibility of the latter.
- Admittedly many lessons have been learned in the twenty years since the presentation of the unsatisfactory results in Korea commemorating the 4th ITTC held at VWS Berlin in 1937.
- At that ITTC Horn and colleagues from Wageningen and Tokyo already discussed related procedures and their first, preliminary results.
- That early development suffered from the inadequate conceptual approach and the poor measuring and computing techniques at that time and has been disrupted by the war.

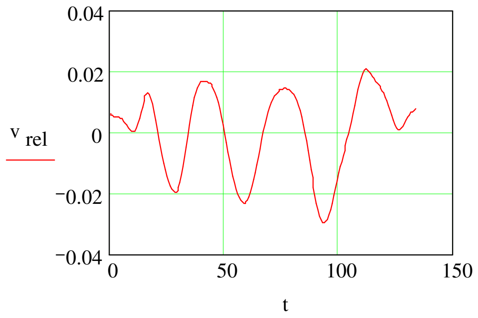
Raw data: surge



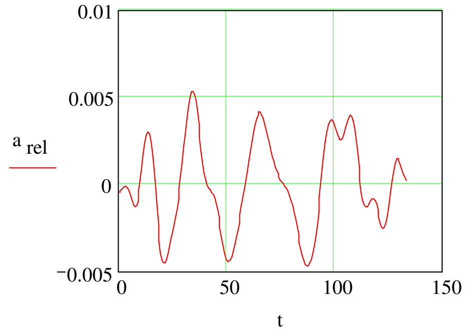
SMP '09 Trondheim	Schmiechen 14

- In monitoring of full scale performance there is no need for artificial changes of the rate of revolution. Any change during operation may serve as reference for the suppression of noise.

'Derived' from surge: speed variation

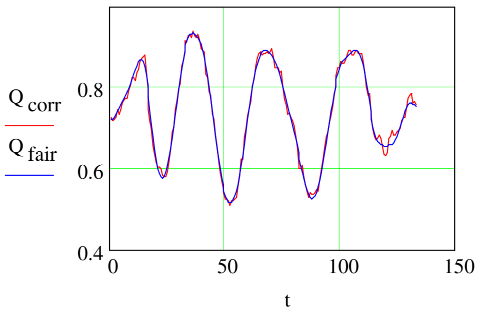


'Derived' from surge: acceleration



- In case of full scale quasi-steady tests the inertial forces provide for the necessary reference.
- In that case the hydromechanical inertia has to be carefully determined.

Raw data: torque



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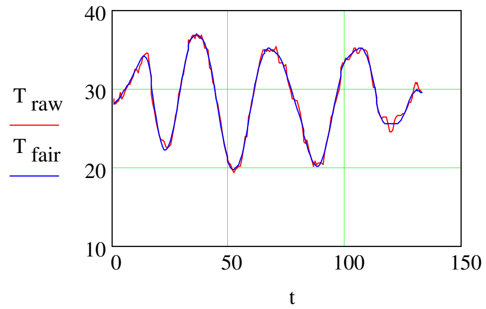
Schmiechen 17

Raw data: thrust



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Schmiechen 18

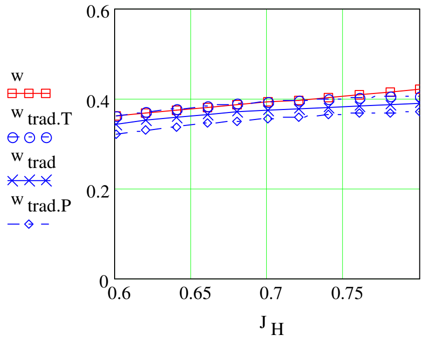
The following slides show only some comparisons of

• results of the rational evaluation based on the propulsion tests alone with

• results of the traditional evaluation based on additional hull towing and propeller open water tests.

•The complete comparison is to be found on my website.

Wake fractions



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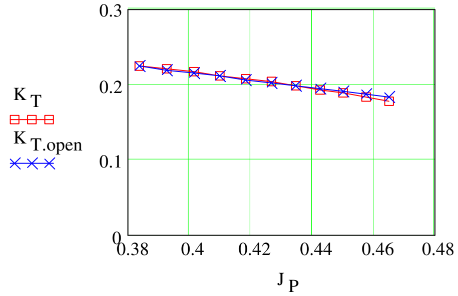
Schmiechen 19

Thrust ratios



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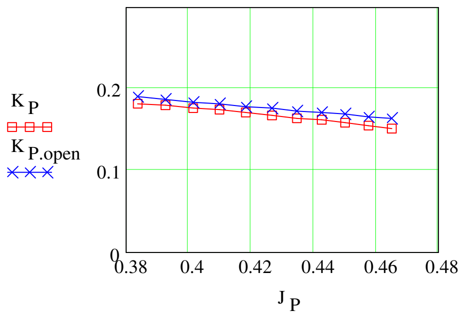
Power ratios $K_P = 2 \pi K_Q$



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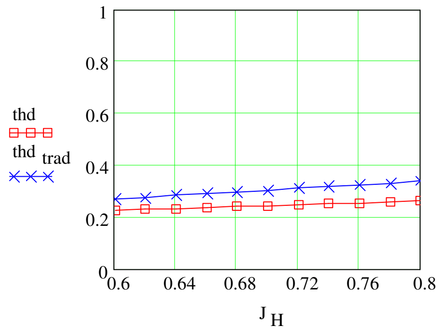
• Thus the coherent model and the coherent set of data recorded during a quasisteady model test of only two minutes duration permit to identify coherent results in a wide range of propeller advance ratios.

• This technique is the only meaningful in case of wake adapted propellers, pre- and post-swirl configurations, partially submerged propellers etc.

Thrust deduction fractions



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• Anybody, not totally blind on both eyes, will see the technological and commercial advantages of the procedure, not even requiring a towing carriage.

• Extended experimental studies necessary for the validation of computer codes and/or optimisations can thus be performed very quickly, very cheaply and, last but not least, most reliably over wide ranges of parameters.

• In one run down a model basin such tests may be performed at various speeds, although at slow speeds the results are felt to be blurred by more scale effects than 'necessary'.

METEOR: Test conditions *1988*

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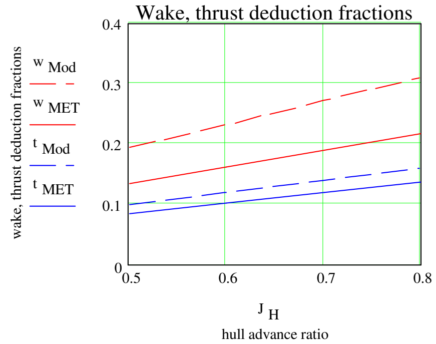
• As has been mentioned the method can be applied on full scale. This has been done with the German research vessel METEOR in November 1988 in the Arctic Sea.

• Please do not *only* refer to this fundamental, now historical work, but notice the various developments in the past twenty years documented in the continued evaluation of the 'model' test shown.

• Quasi-steady tests have also been performed on model and full scale with the experimental air-cushion vehicle CORSAIR/MEKAT of B+V fitted with partially submerged propellers.

• And the technique outlined will used by MARIN and Wärtsilä.

METEOR: Scale effects *1990*



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• Results of the full scale tests with the METEOR have been compared with results of corresponding model tests

• providing scale effects in wake and thrust deduction fractions, for the first time worldwide.

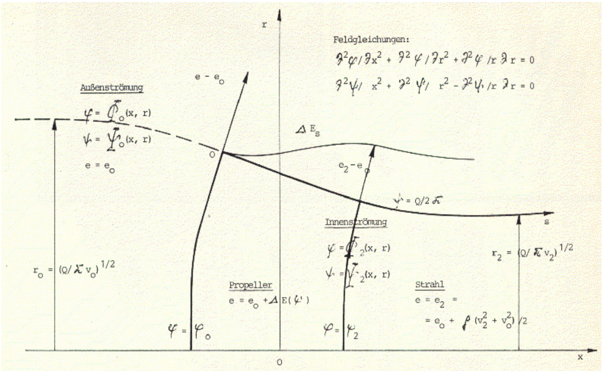
• I am always surprised that naval architects remain seated when I tell this,

• although these scale effects are the corner stones of reliable powering performance predictions.

• So far I have dealt with the rationalisation o Froude's methodology.

• I will now turn to problems where this methodology is no longer applicable.

Ideal 'ducted' propeller *1978*



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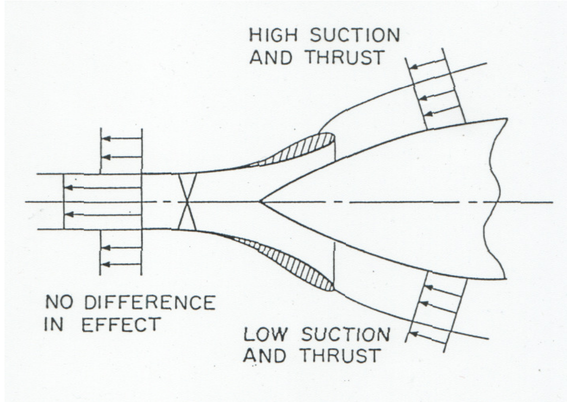
• Most expositions of the theory of ideal, open and ducted, propellers are quite inadequate and misleading, based not on elementary hydrodynamics, but rather on professional superstition.

• The reason is that causes and effects are not clearly distinguished and that the only propeller model traditionally introduced, the actuator disc, is inadequate for most purposes.

• A singular actuator disc suffers not only from edge singularity, but more importantly,

• it obscures the fact, that the same ideal jets may be produced by 'more realistic' equivalent potential force fields.

Nasty by-products *1961/ ONR'68*



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• Most design methods are still concerned with ducted propellers in open water.

• And the methods to deal with hull-propeller interactions are much too crude, to say it politely.

• In view of the fact that interactions mostly take place between hull and duct the traditional approach is neither realistic nor acceptable.

• Suction at the hull and thrust at the duct constitute an energetically neutral hydrodynamical short circuit as noted already by Busmann in 1935.

• Consequently thrust is no longer a meaningful design goal and performance parameter,

• and thus computing thrust deduction fractions is not particularly meaningful.

Propulsors as pumps *1983, 1992*

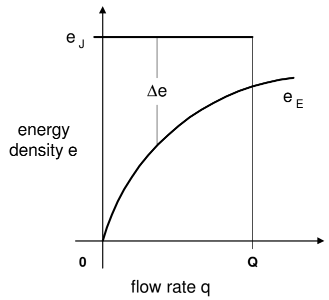
In cases of hull integrated propulsors hulls and propulsors can no longer be separated, <u>not even conceptually</u>.
An adequate and efficient conception is to treat propulsors as pumps *establishing the condition of self-propulsion at the design speed.*
As simplest examples of such propulsors ducted propulsors have been treated.

• To consider propulsors as pumps is not just another approach, but it addresses the 'real' problems and offers dramatic advantages.

• Instead of looking at the short circuit between hull and duct it is much more efficient to look at the output generated.

Design goal: <u>net</u> thrust

'Invariant' design goal for **all equivalent optimal, wake adapted ducted propellers including all hull-duct-propeller interactions!**

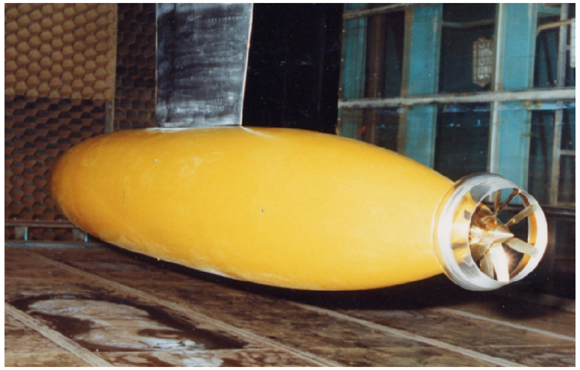


• As in pump design everything else is being dealt with in terms of energy flows,

• the thrust and all interactions are being treated implicitly observing the condition of optimum propulsion from the beginning,

• the thrust comes in explicitly only at the end, as a nasty by-product.

‘Pump’: behind *Amtsberg's* ‘cigar’, *1992/3*



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• At the time of our project we did not have the CFD capabilities for the blade design you now have at your finger tips.

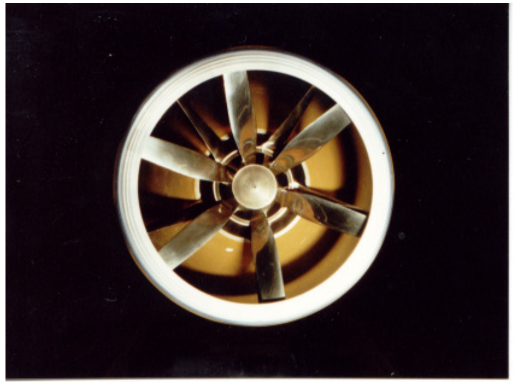
• I often hear the question: Has somebody else tried any of the procedures proposed?

• You can imagine how impressed I am with this incredibly creative and innovative attitude.

• My answer is: Yes, some institutes already started to apply my methods.

• But most of the colleagues are still waiting for somebody else to outsmart them and take advantage of the power tools developed to maturity.

Towards the future: *follow me!*



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• The 'only' sensible question is: If all this has already been done, what can be and what needs to be done next? What can be done, impossible to be done before within the traditional framework, which has caused the problems?

And the answer is:

• Take competitive advantage of the concepts, of the solutions already developed and of the power tools provided for the solution of other problems at hand, among them:

the design and evaluation of efficient research strategies and test techniques,

the design of appropriate facilities,

the construction of adequate performance criteria etc etc.