

Optimization Using Surrogates for Engineering Design

Mark Abramson, USAF Institute of Technology

Charles Audet, Gilles Couture,
École Polytechnique. de Montréal

John Dennis, Rice University

Andrew Booker, Evin Cramer,

Paul Frank, Joerg Gablonski, Boeing Phantom Works ■

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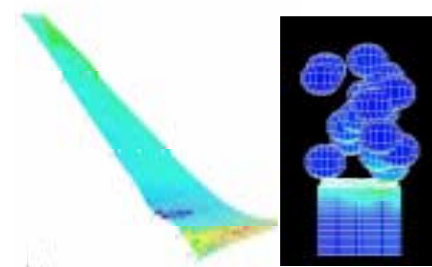
Design Explorer Applications



Helicopter Rotor Design



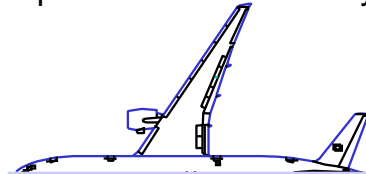
Space Station Power System



Shot peen forming of wing skins



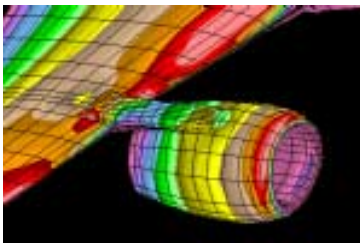
Aerospike Nozzle



Multidisciplinary wing
planform design



3-D Fighter Aerodynamics



Engine Nozzle
Performance



777 Engine Duct Seals



Machining, riveting, and drilling database

A strawman surrogate approach

1. Choose surrogates s_f and S_C based on either:
 - (a) simplified physical models; or
 - (b) surfaces obtained from f, C values at selected sites ■
2. Minimize $s_f(x)$ for $S_C(x) \leq 0$ to obtain x_s .

Every user has their favorite approach for this part ■
3. Compute $f(x_s), C(x_s)$ to determine if improvement has been made over the best x found to date ■

But, what if no improvement was found?

Response surface global models

- ◆ Choose a space filling set of points – say by Latin hypercube or orthogonal array sampling
- ◆ Run the expensive simulations at these sites
- ◆ Interpolate or smooth to f, C on this data
- ◆ May be able to interpolate to gradients as well – Alexandrov

Form of the DACE interpolants

Polynomials introduce extraneous extremes that trap strawman ■

Spline-like DACE interpolants can be written

$$\hat{s}(x) = \sum_{i=1}^d w_i(x) f(x_i) \quad \blacksquare$$

DACE predictions at any x are weighted averages of f at the data sites. Weight depends on how far site is from x . ■

Correlation parameters for each site estimated by MLE.

Surrogate Management Framework

Given initial surrogates s_f, s_C and $p_0 \in M_0$, a grid on \mathbb{R}^n , let $P_0 \subset M_0$ be p_0 and the points of M_0 adjacent to x_0 ■

For $k = 0, 1, \dots$, do ■

1. (Strawman) Search on s_f, s_C to find an unfiltered $x_{k+1} \in M_k$ and then set $M_{k+1} = M_k$ and update the surrogates; ■
2. Else if p_k is the only unfiltered point in P_k ; Then set $x_{k+1} = x_k$ and $M_{k+1} = M_k/2$ and update the surrogates; Else return to 1

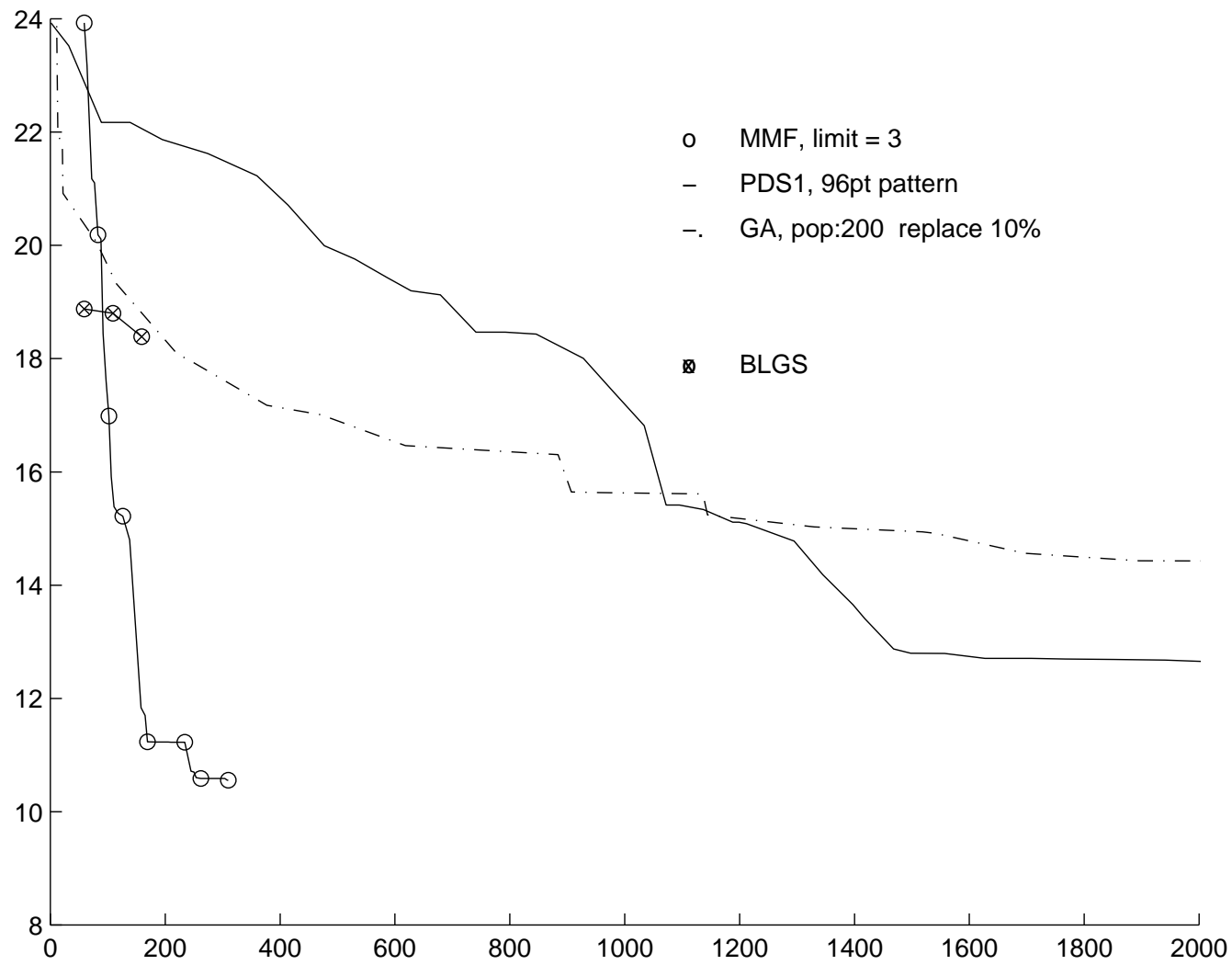
Just like FPS, but...

Poll step: Polling is done on the actual (barrier) functions, which guarantees convergence of the algorithm (through the sequence of unsuccessful poll steps).

Search step: Use surrogates s_f, S_C to find some promising candidates where f, C will be evaluated.

Update s_f, S_C with the new evaluations of f, C .

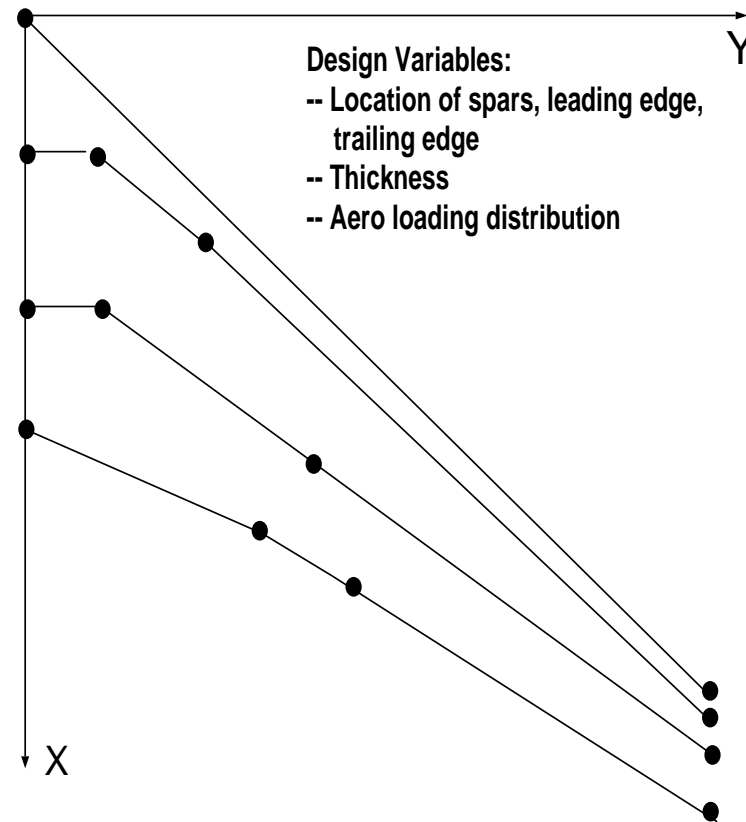
Comparisons on 31d helicopter example



Boeing wing planform design

Infeasible baseline design.

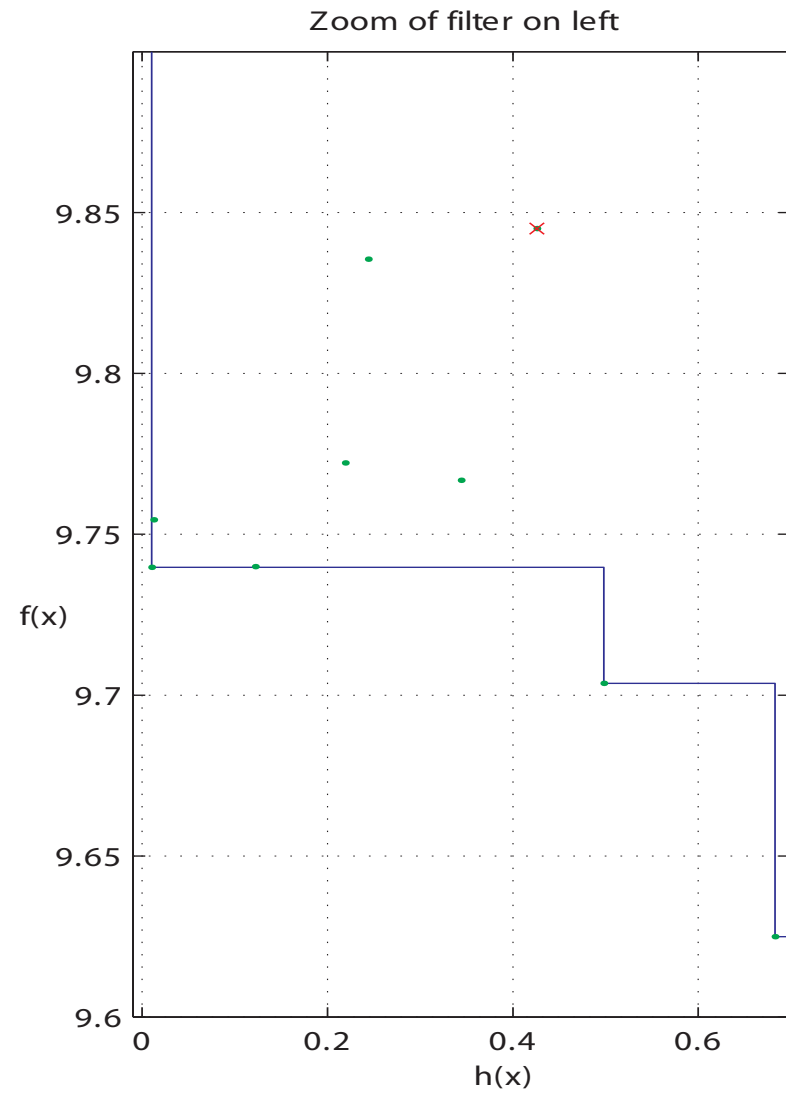
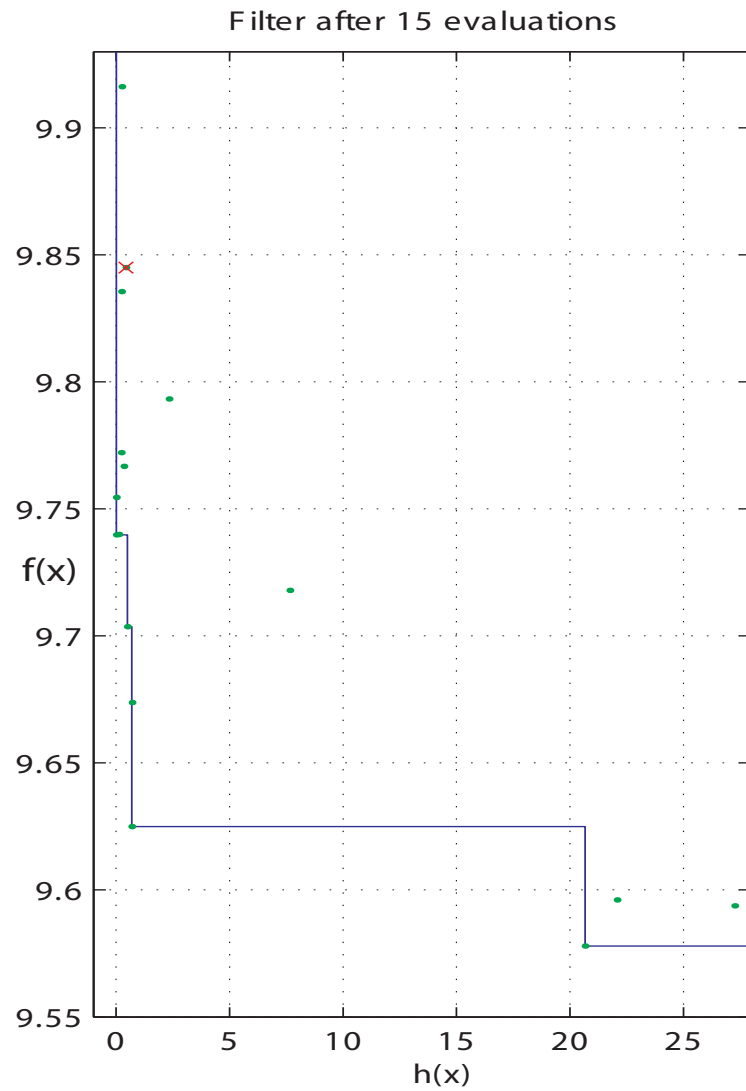
	n	# of ctrs	# of fevals
A	15	11	304
B	15	11	292



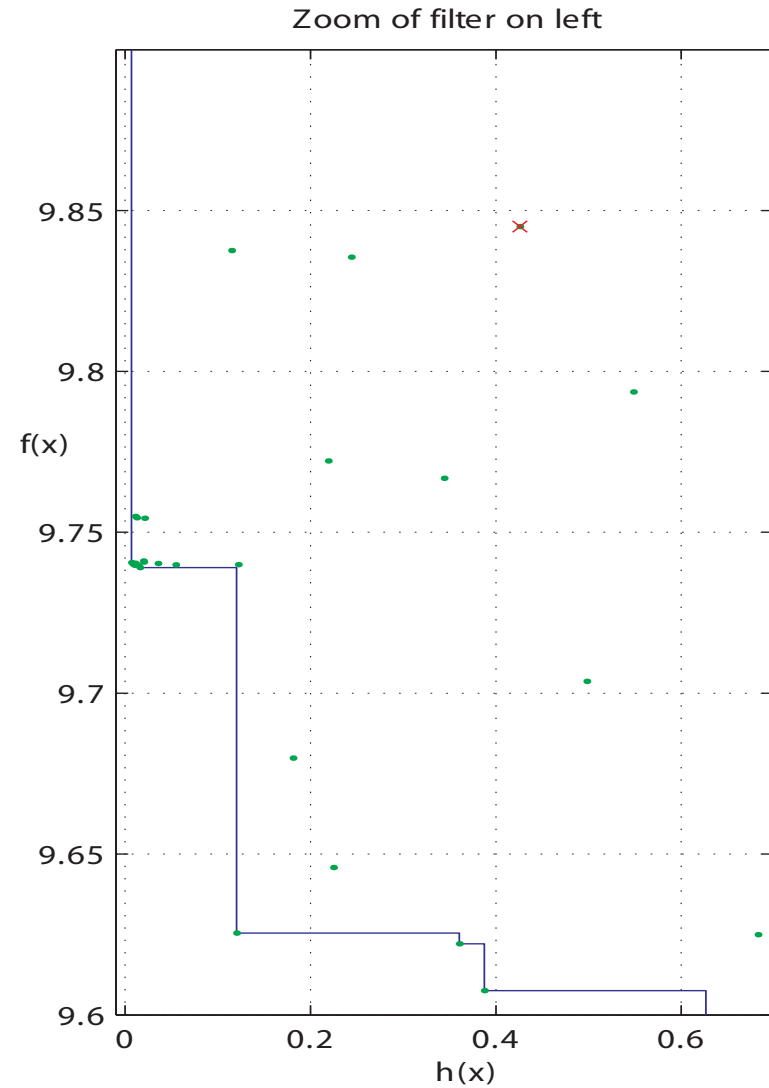
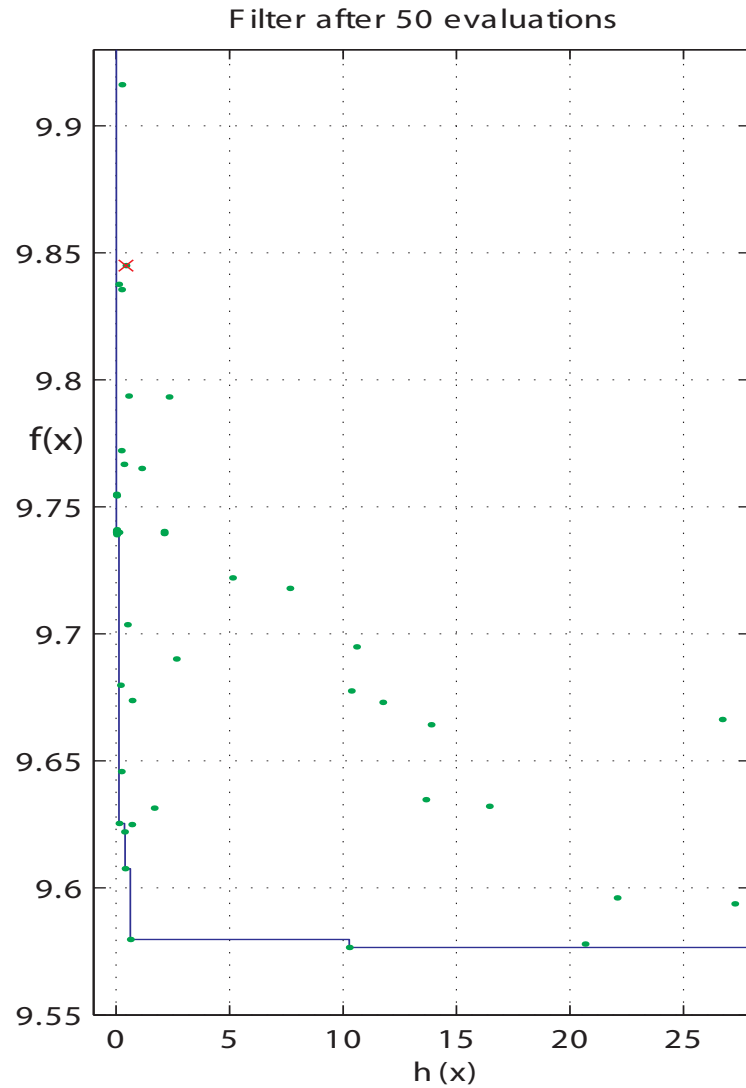
New Boeing SonicCruiser platform



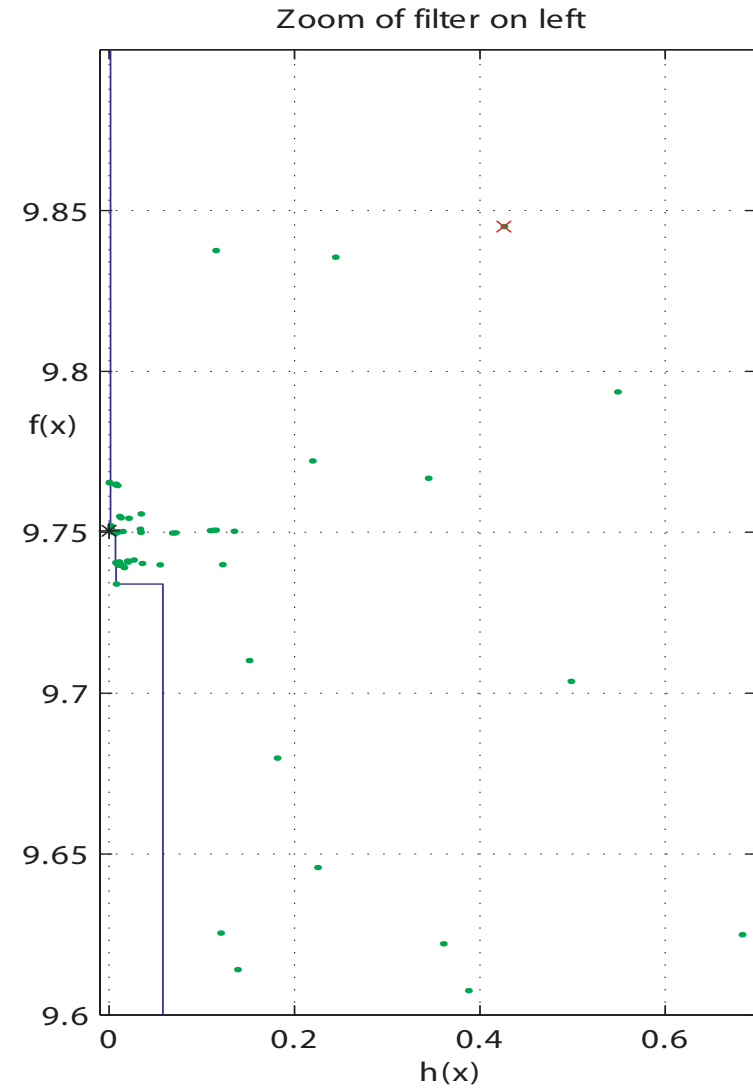
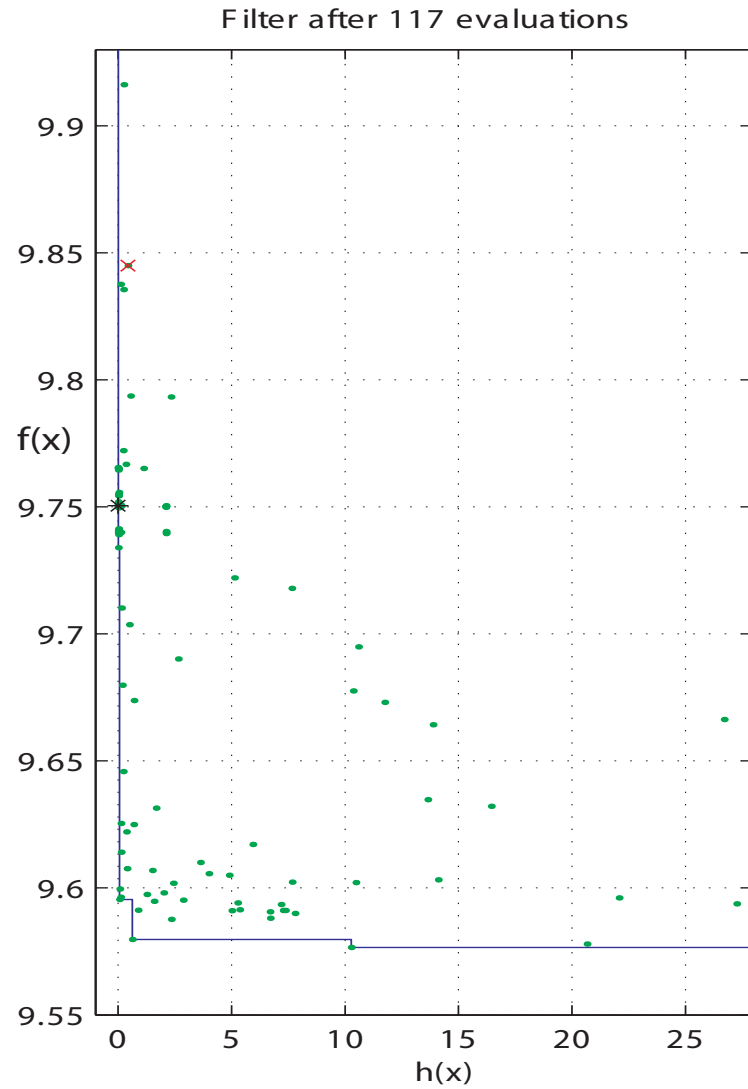
A planform filter



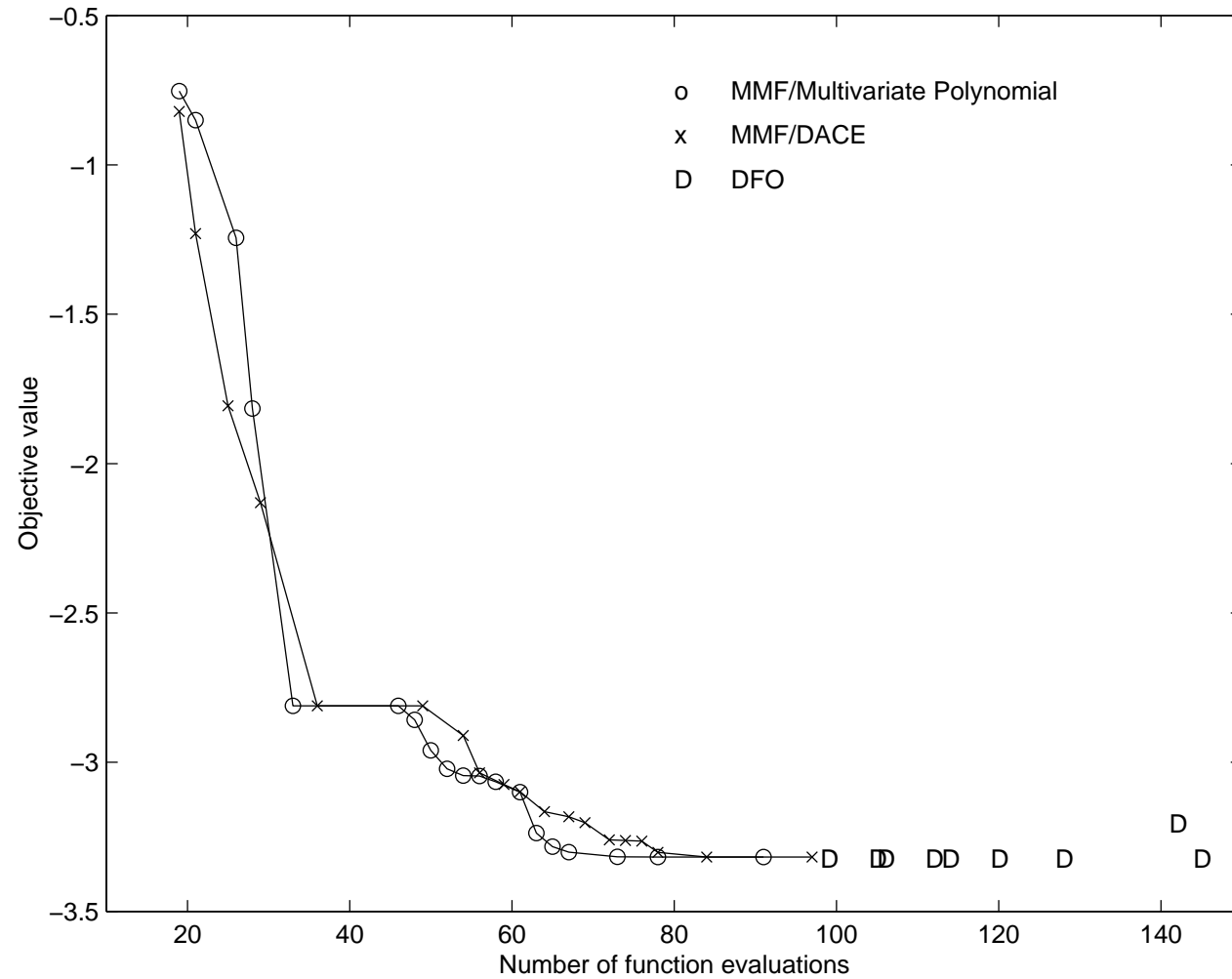
A planform filter



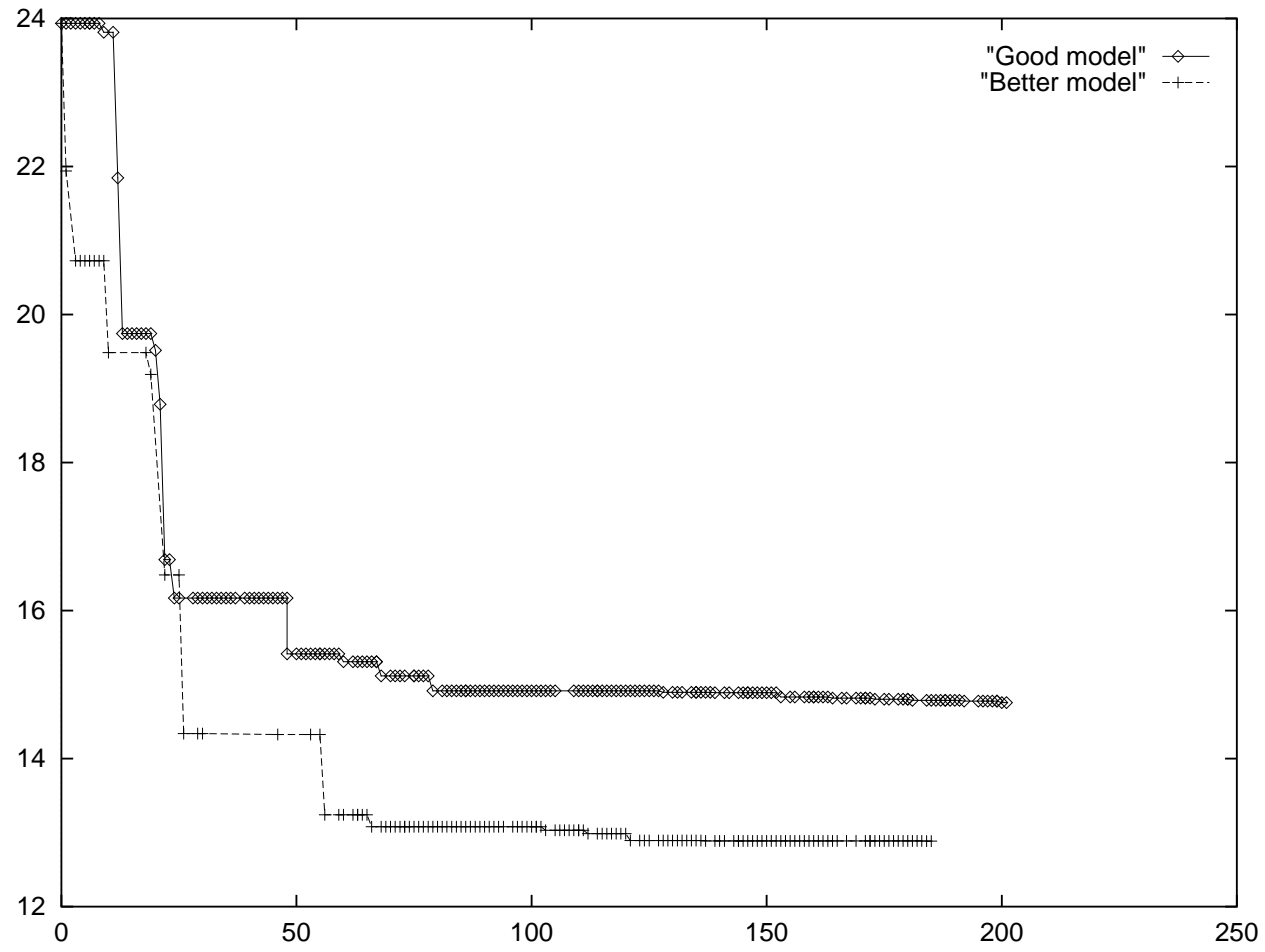
A planform filter



Polynomial vs DACE surrogates



Recovering from a bad surrogate



Software

- ◆ A simplified algorithm with local steps only is used 100k times each day in Boeing's commercialized 2NA parts nesting software
- ◆ Design Explorer is a Boeing proprietary implementation of our SMF with proprietary surrogates and a specialized search. Commercialization is underway

NOMAD

- ◆ Current NOMAD C++ implements the filter approach. Presently in production use at ExxonMobil. Available to beta users
- ◆ NOMADm is a downloadable MatLab implementation in production use at Seimens VDO for designing engine control laws
- ◆ Should handle uncertainty optimization models

Conclusions

- ◆ Clarke's nonsmooth analysis tools simplify, shorten, and strengthen the pattern search analysis
- ◆ Filters handle nonlinear constraints without using derivatives, Lagrange multipliers or penalty parameters
- ◆ SMF seamlessly incorporates user heuristic SEARCHES, and POLLING provides robustness and rigor
- ◆ SMF needs less accurate surrogates than designers want anyway

Plans

- ◆ Boeing and ExxonMobil want more design variables than present interpolatory surrogates can handle. Requires rethinking the surrogate/optimization interface. High payoff, high risk, high entertainment value ■
- ◆ Put filter approach to categorical variables from NOMADm into NOMAD and test on pipe bending problems. Open ended, high entertainment value

Plans

- ◆ Use crude/inaccurate (stochastic(?)) derivatives to increase efficiency. Low risk, possible high payoff■
- ◆ Put NOMAD into Boeing Design Explorer. High payoff, low risk■
- ◆ Parallelize NOMAD. Open ended , high payoff, low risk■
- ◆ Use NOMAD or Design Explorer to investigate various uncertainty formulations and explore tighter integration

Recommendations

- ◆ Learn the client's language and listen to them■
- ◆ Learn how your client gets praise, raises, promotions■
- ◆ Learn all you can about optimization, statistics, linear algebra, software engineering and numerical methods■
- ◆ Don't change the problem to fit the mathematics you know, develop the mathematics the problem needs

Finally

Academics are people who expect to be rewarded for what they plan to do, not what they have done. Don't be that way.■

Don't expect support up front. Remember, even meeting with you to formulate a joint project is support.