Optimization Strategy for Air Bearing Systems in Hard Disk Drives

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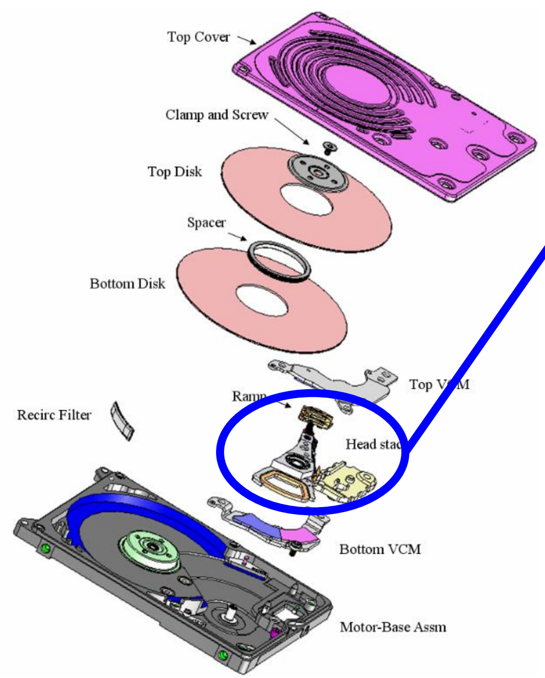
Background: General

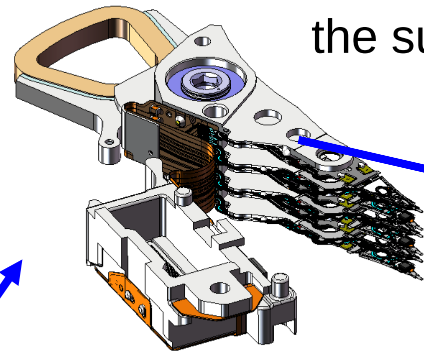
- Digital storage industry:
  - **Hard Disk Drive**
  - SSD

- Exploding digital Universe
  - 2007: 281×10^{18} (281 Exa) Bytes (about 45 GB per person)
  - 2012: 2.5×10^{21} (2.5 Zetta) Bytes
  - More than 95% of the 450 Exa Bytes of storage shipped in 2012 will be magnetic **hard disk drives (HDD)** (source: IDC)
  - **The total amount of data stored (all media) in the world doubles every two years**
    - Approximately 390 GB of data are created every second today
    - 500 GB of data created every micro second by 2020

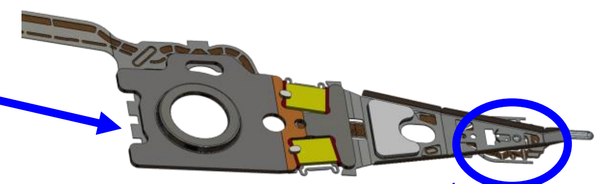
Background: our focus in HDD: ABS = Air…. What ?

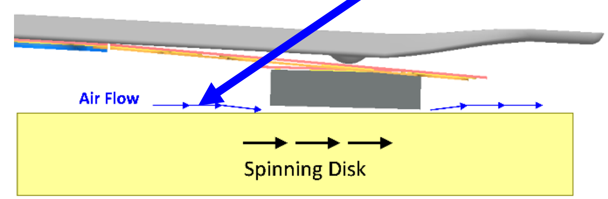
Extremely complex
technological object





We focus on the read/write
head at the extremity of
the suspension





The spinning disk
drags air
The air flow supports
the head

Air Bearing System
(Tribology)

Background: Challenge of an ABS

- Dynamically controls the interface between the head and the disk
- Same idea as a plane…
  The head is flying above the disk

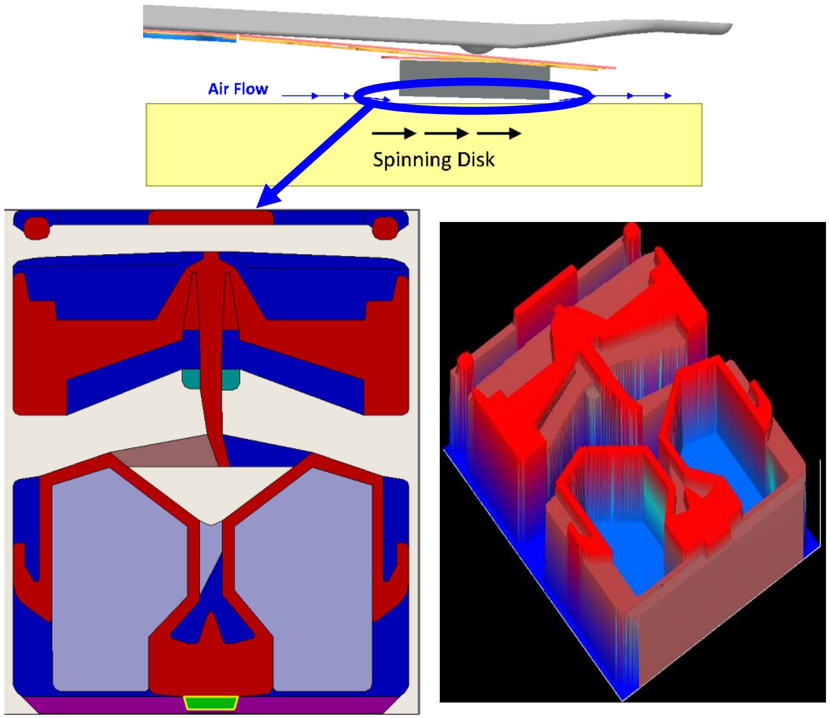
- **… With much more challenging conditions and requirements**
  - In 1974, the head flying height was equivalent to a Boeing 747 airliner flying at 6 inches above the ground
  - In 2006, the 747 has to fly at 0.015 inches (0.4 mm)
  - Air flow much stiffer than atmospheric air
  - Complex set of **Tradeoff** to satisfy

ABS Design Trade offs

Improved Feature	Ability to follow the disk surface topography	L/UL	ABS TD Stability	Altitude / Humidity Margin	Op-shock Margin	Particle Margin	Servo Seed/Fill RPM sens.
Knobs	■ High (+) TE Pressure ■ High Pitch	■ Reduced (-) pressure (lower unload force). ■ Retracted Rails	■ High Pitch ■ Surface Texture ■ Higher stiffness air bearing (higher +and – pressure)	■ Low Pitch ■ High Crown ■ Reduced Particle Fence ■ Shallow cavity etch depths.	■ Higher stiffness air bearing (higher +and – pressure) ■ Retracted Rails	■ Low Pitch ■ Low Crown ■ Particle Fence	■ Deeper cavity etch depths.
Degrades →	1. Lube Disturbance 2. Particle Margin 3. DFH Efficiency	1. Roll stiffness	1. Altitude / Humidity Margin 2. Particle Margin 3. Op-Shock Margin	1. Particle Margin 2. ABS Stability 3. L/UL 4. Servo seed/fill RPM sens.	1. Lube Disturbance 2. Particle Margin 3. L/UL	1. Altitude / Humidity Margin 2. ABS Stability 3. L/UL 4. Op-Shock Margin	1. Altitude / Humidity Margin

Background: Optimization pattern

Input (ABS Design)



Output (Performance tradeoff)

Optimization

Improved Feature	Ability to follow the disk surface topography	L/UL	ABS TD Stability	Altitude / Humidity Margin	Op-shock Margin	Particle Margin	Servo Seed/Fill RPM sens.
Knobs	▪ High (+) TE Pressure ▪ High Pitch	▪ Reduced (-) pressure (lower unload force) ▪ Retracted Rails	▪ High Pitch ▪ Surface Texture ▪ Higher stiffness air bearing (higher +and – pressure)	▪ Low Pitch ▪ High Crown ▪ Reduced Particle Fence ▪ Shallow cavity etch depths.	▪ Higher stiffness air bearing (higher +and – pressure) ▪ Retracted Rails	▪ Low Pitch ▪ Low Crown ▪ Particle Fence	▪ Deeper cavity etch depths.
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- So far, design was done manually → **Set up a systematic approach**
- Primal flying characteristics:
  - Fly Height (FH): Flying altitude
  - Pitch (P): vertical incline angle
  - Roll (R): horizontal incline angle

Outline of the optimization process

- Optimization Strategy
- Outcome
- Conclusions / Next steps

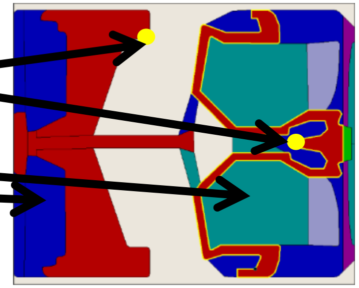
Optimization steps

Design Space

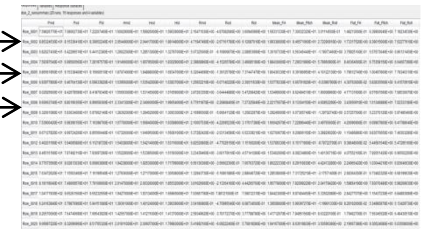
Generate DOE matrix with designs to investigate

Points in 2D space

Etch depths



Design1
Design2
Design3
…



DOE computation

Run all the cases, as fast as possible

Running thousands of jobs
Average job time per CPU: 18 min

Response surface

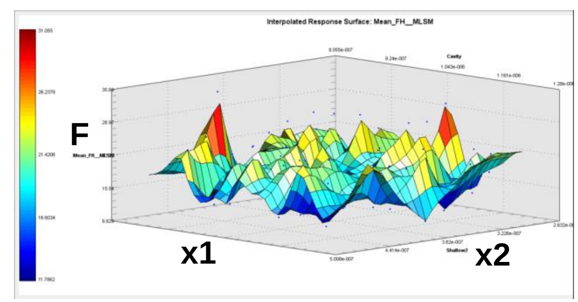
Compute a function that mimics the solver response

Time: 10 min

Inputs → Solver → Outputs

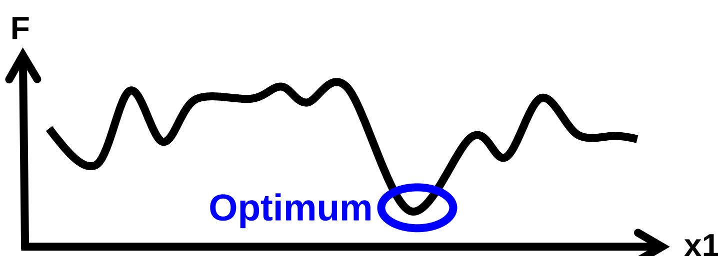
$$F(x) = \sum_{j=1}^{N} \alpha_j g_j(x) + \alpha_{N+1}$$

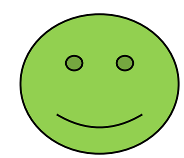
Time: 10 ms



Optimum search

Find the function optimum regarding performance objectives





Ingredients for success

- Optimization scheme only tells how to optimize, but not how to **optimize well**

Baking analogy: 4 steps, and good practices

- ***Gather ingredients:***

Design Space

- ***Mix:***
- ***Bake:***

DOE computation

- ***Icing:***

Response surface

Optimum search

Ingredients for success

- Optimization scheme only tells how to optimize, but not how to **optimize well**

Baking analogy: 4 steps, and good practices

- ***Gather ingredients:*** Choose parameters

  Set range for each parameter — Design Space

- ***Mix:*** Combine them
- ***Bake:*** Get enough computational power

  Run all simulations reliably — DOE computation

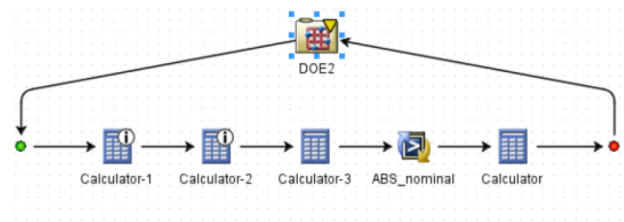
- ***Icing:*** Build a good response surface — Response surface

  Find a good optimum — Optimum search

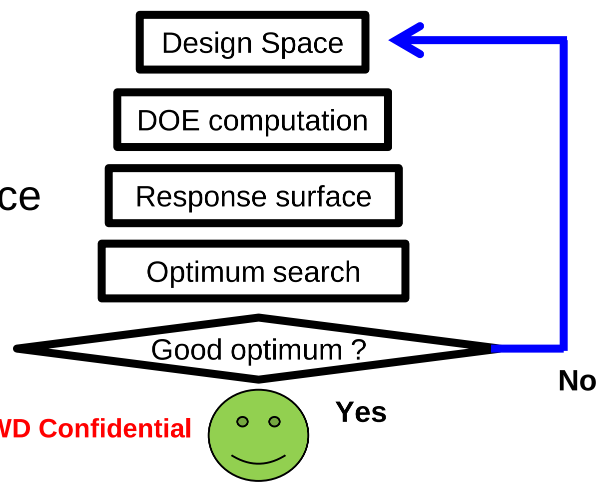
Investments

- **Hardware:**

- **Software: Isight®**
  - Design generation
  - Response surface
  - Optimum search



- **In house post process packages:**
  - Iterative process
  - Guidelines to readjust the design space for the next step



Outline of the optimization process

- **Optimization Strategy**
- **Outcome**
- **Conclusions / Next steps**

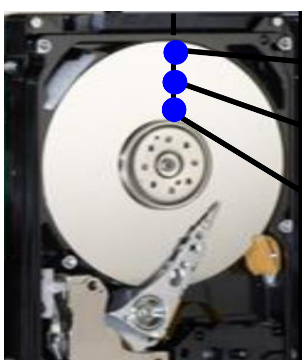
Simplified optimization DOE example.

- **DOE setup:**

Performances addressed	Count	Runs required	Original			Goals
FH	3	1	…	…	…	**< 1nm (10nm av.)**
Crown sens	1	2	…	…	…	**Decrease**
Pitch	3	0	…	…	…	**Preserve**
Roll	3	0	…	…	…	
Pushback	3	1	…	…	…	
Roll sens	1	4	…	…	…	
Altitude	3	1	…	…	…	
Z-height sens	3	2	…	…	…	
Z crossover	1	5	…	…	…	
Total	**21**	**16**				

Goal: Improve FH profile flatness, and crown sensitivity without affecting other parameters.

- **Assessment of performance profile through the radius spectrum**



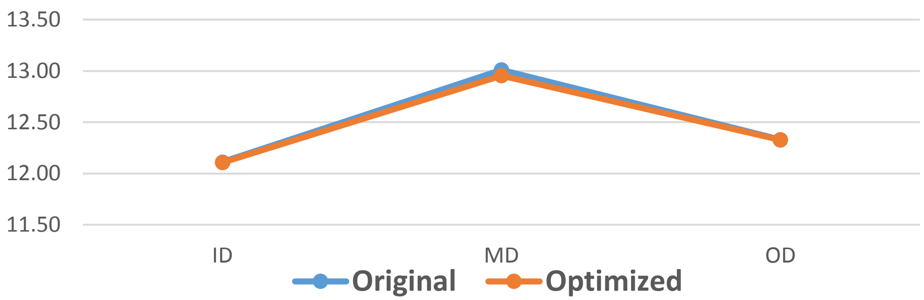
Result at Outter diameter (OD)

Result at Middle diameter (MD)

Result at Inner diameter (OD)

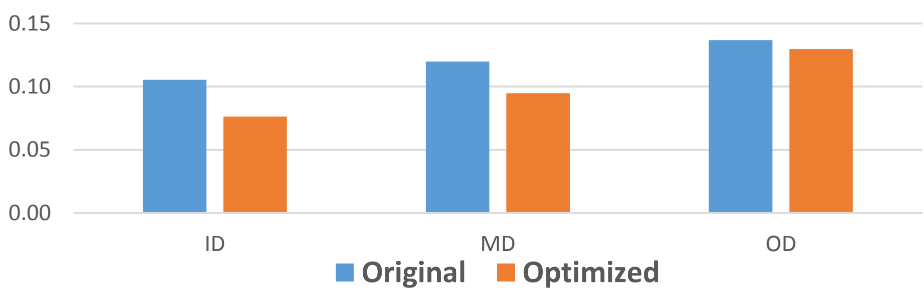
Some concrete example of improvement

- **Fly Height**



FH flatness preserved

- **Crown sensitivity**



28% improvement at ID: Very significant

- **Other key performances improved …**

Outline of the optimization process

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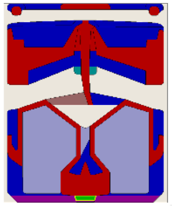
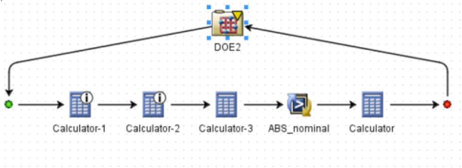
- **Conclusions / Perspectives**

Conclusions / Perspectives

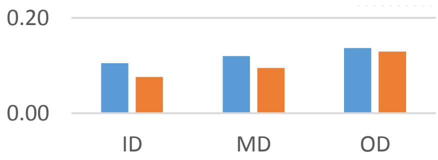
- **Conclusions:**
  - Systematic approach to optimize ABS designs.



  - Strategy involves Isight® and packages around



  - Better tradeoff reached



  - Some optimized designs are being ordered for testing

- **Perspectives:**
  - Using Simulia Execution Engine to simplify job submission to remote servers