# Advancing Product Lifecycle Management through Multi-Disciplinary Optimization

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# Outline

- Introduction
- Stage 1:Strong and weak coupled MDO problem
- Stage 2:Stochastic MDO
- Stage 3:Approximation methods
- Conclusion

# Mission of our lab

- MDO research in our lab is designed to handle the problem of both strong and weak coupled questions
- MDO research in our lab is based on the integrated simulation
- MDO research in our lab is dedicated into overcome the disadvantage of the current MDO

To be continued…

# Disadvantages of MDO

- Designers need to have knowledge in every discipline
- Time and resource consuming. BMW has reported needing 1,200 CPU months to solve an MDO problem involving FEA and coupled dynamics
- It is difficult to get a global optimized answer

**To overcome the problems above, we are conducting MDO research in this lab. We believe we are working at the leading edge of the field.**

$y_1 = a_1(x, y_2)$
$y_2 = a_2(x, y_1)$

# Classification of MDO Problems

- All MDO Problems can be classified into strong or weak coupled problems according to relationship among the disciplines.

- X is design vector which every disciplines shared. $y_1$ and $y_2$ are state vectors which are functions of design variables. For example, area $S = l \times h$ , S is state variable.

- *Strong coupled*

$$y_1 = a_1(x, y_2)$$
$$y_2 = a_2(x, y_1)$$

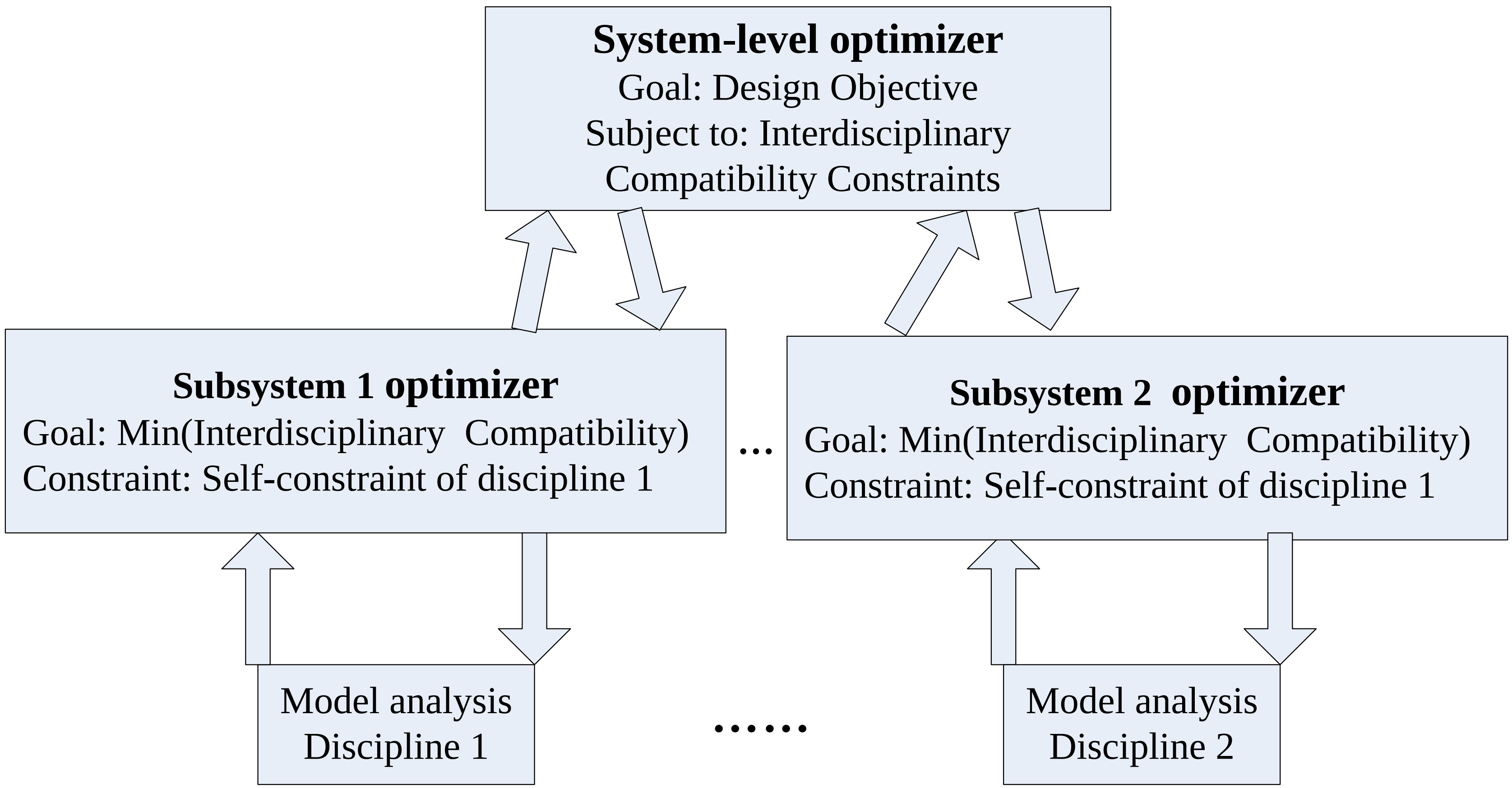
- *Weak coupled*

$$y_1 = a_1(x)$$
$$y_2 = a_2(x, y_1)$$

or

$$y_1 = a_1(x)$$
$$y_2 = a_2(x)$$

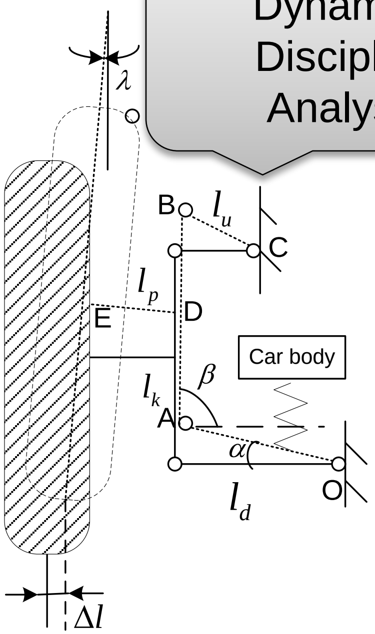
# Weak Coupled Problem--Collaborative Optimization



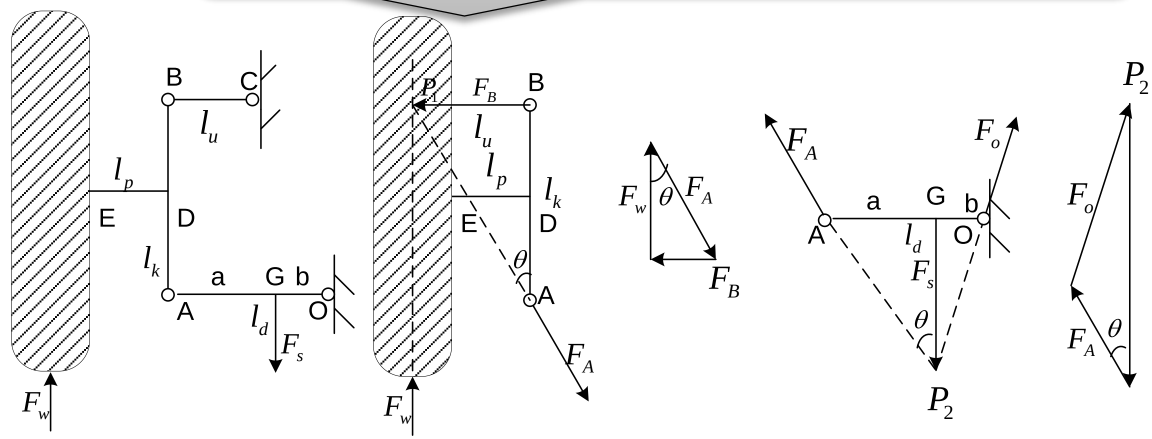

Stage 1

# Application on active suspension

Dynamics Discipline Analysis




Structure Discipline Analysis



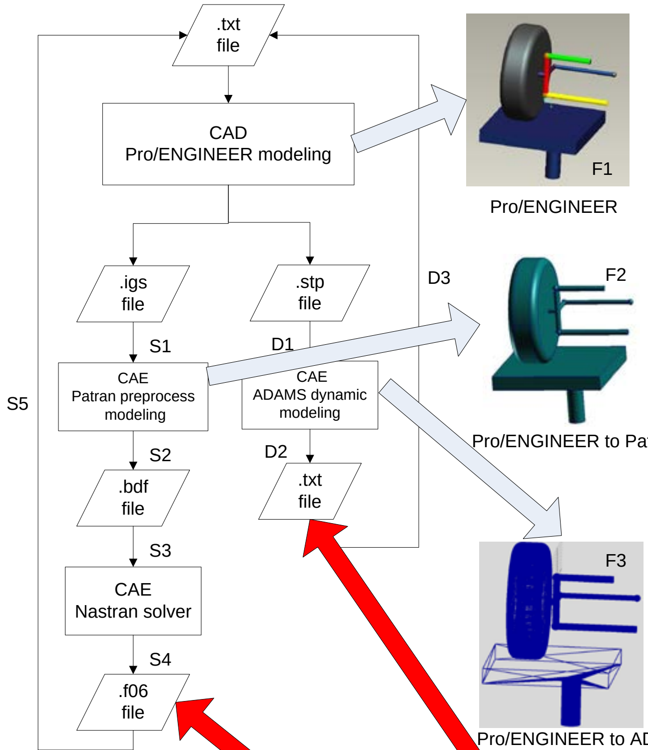

(a) (b) (c) (d) (e)

The slip displacement of wheel should be not more than 5mm. This is the allowable displacement of elastic deformation.

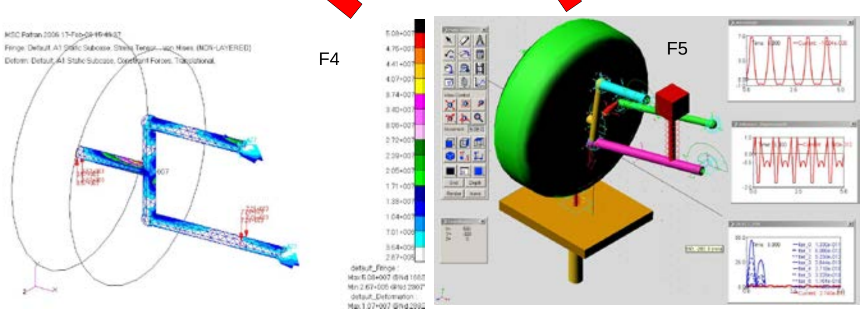
The constraint is that maximum stress tensor is smaller than the yield one.

Stage 1

# Data transmission and result

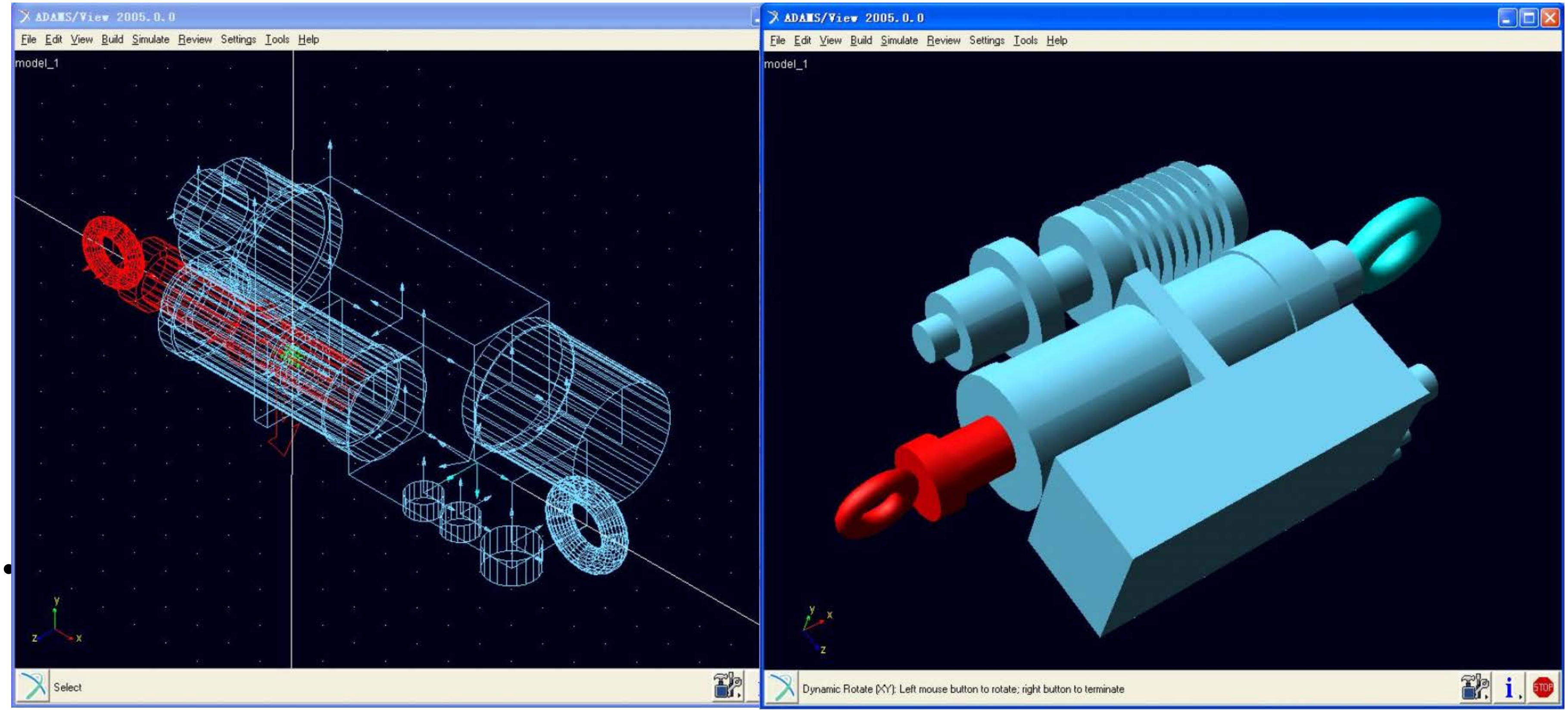



| Parameter | Initial value | Min value | Max value | Result of optimization | Unit |
|---|---|---|---|---|---|
| $l_u$ | 35 | 26 | 38 | 36.26 | cm |
| $l_d$ | 50 | 40 | 58 | 41.65 | cm |
| $l_k$ | 32 | 28 | 40 | 31.28 | cm |
| $l_p$ | 26 | 20 | 30 | 24.50 | cm |
| $d_u$ | 40 | 30 | 50 | 38.05 | mm |
| $d_d$ | 40 | 30 | 50 | 41.60 | mm |
| $d_k$ | 40 | 35 | 45 | 34.80 | mm |
| $d_p$ | 40 | 35 | 45 | 40.40 | mm |
| $a$ | 40 | 35 | 50 | 33.60 | cm |
| $\lambda$ | 12.5 | | | 1.8 | mm |
| $\sigma_{max}$ | 97 | | | 50.8 | MPa |
| $G$ | 14.3033 | | | 11.0826 | Kg |




With the CO method, we can get the mass of the suspension has deceased by 22.52%. The dynamic and structure performance of the system are greatly improved.

# Strongly Coupled Problem
# - Integrated Simulation

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Stage 1

# Analysis of the Strongly-Coupled System

- Analysis of an Electric-Hydraulic Actuator (EHA)

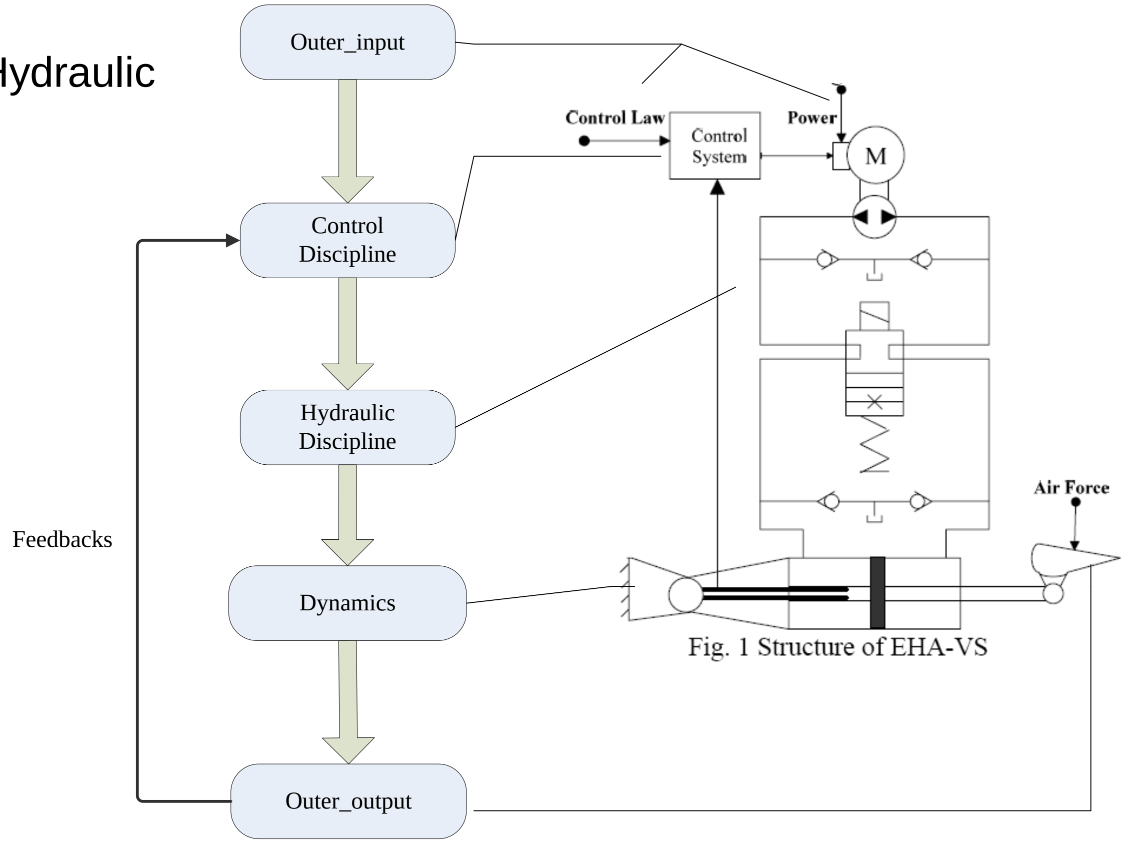
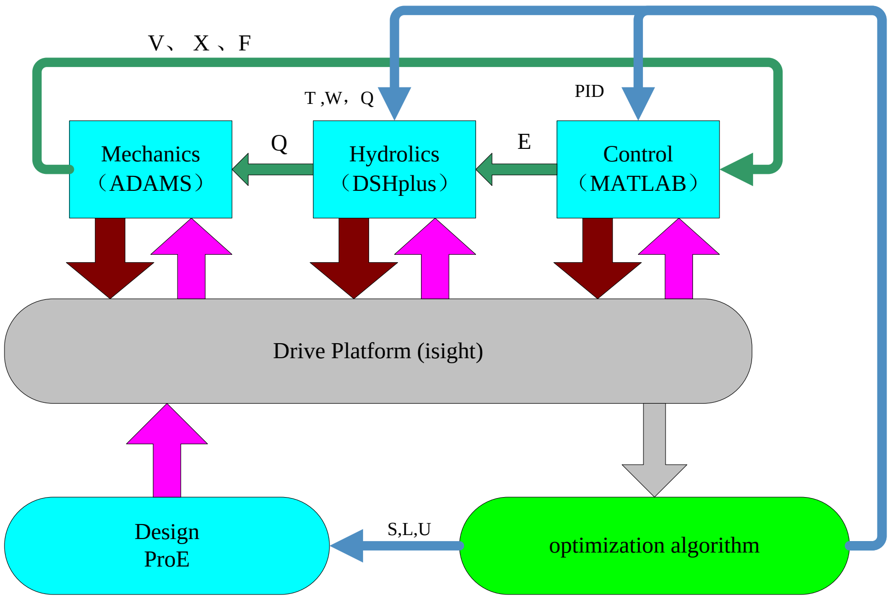



Fig. 1 Structure of EHA-VS

- An integrated simulation method is designed to describe this type of coupled system

Stage 1

# Integrated Simulation Platform



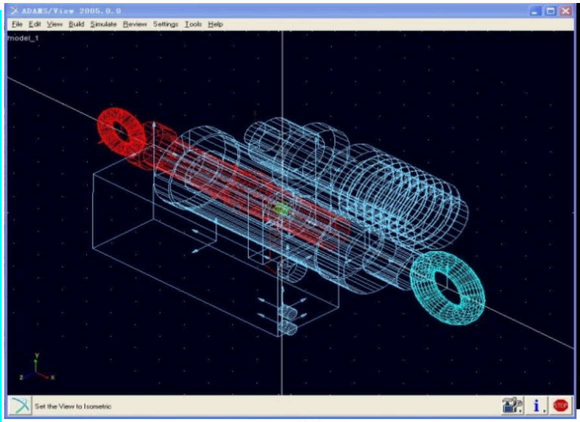

- The Drive Platform runs the simulations multiple times as part of its optimization algorithm. The result is and optimum design as described the design variables
- Design Variable Vector: X=(x1,x2,x3,…Xn) → Generic Algorithm

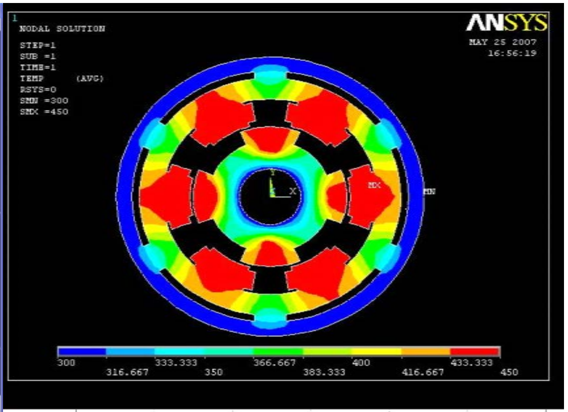
Stage 1

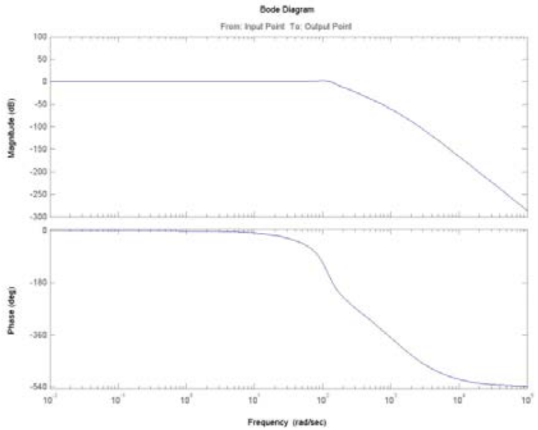
# Optimization Results

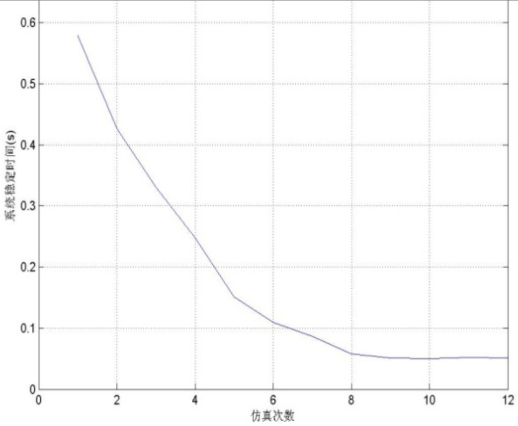
Find the design variable set among three disciplines to get the minimum response time and total mass

p=30;
i=10;
Rc=1Ω;
c=0.18;
Jm=0.00149;
Jp=0.00012;
Kf=0.0002;
Kv=0.002;
p1=2;
i1=2;
p2=1.5;
i2=1.5;
M=10;
PD=100;
DV=5bar;
IM=0.



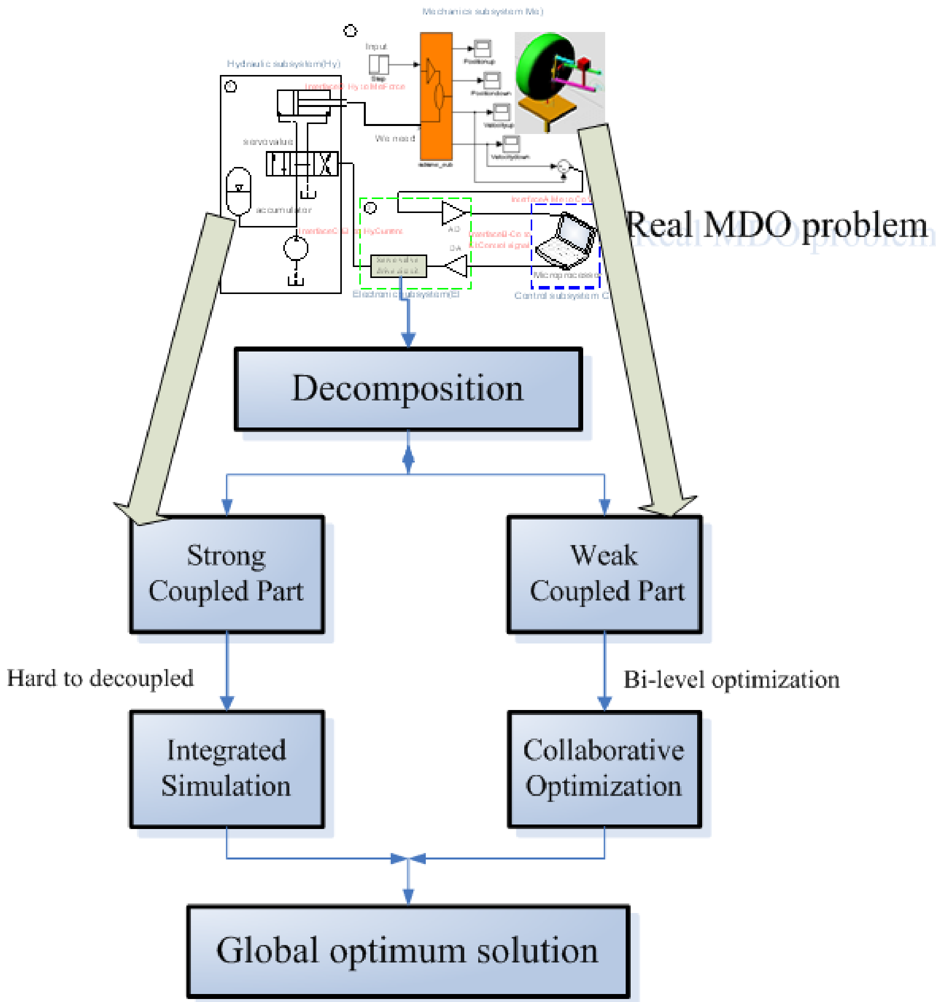



Stage 1

Here, we introduce the platform to solve a real problem that contains both strongly and weakly coupled problems




Stage 1

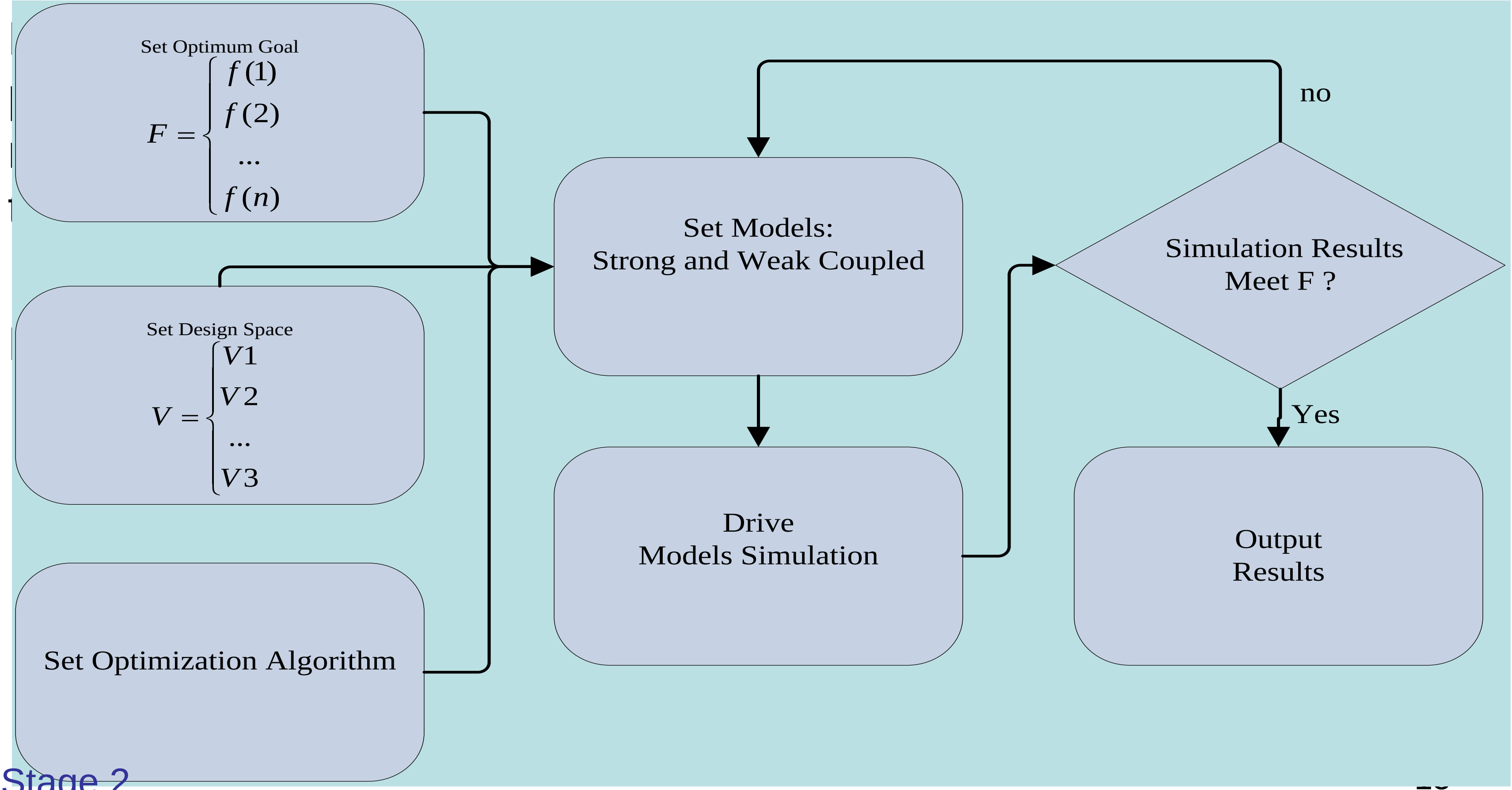
# Short Summary

Stage 1: How do we express the real engineering design mission in our optimization models?

Stages 2 and 3:

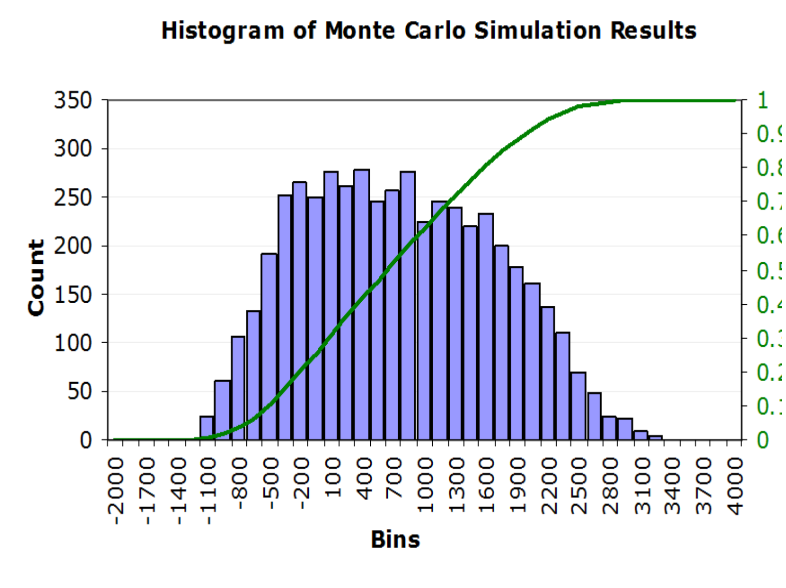
- How efficient can our optimization process be?
- How accurate are the optimization results?

# Introduce --
# Design Space Sampling, Sensitivity Test & Response Types



# Design Space Sampling

## *Stochastic Methods*




**Summary Statistics**

| | |
|---|---|
| Sample Size (*N*): | 5000 |

***Central Tendancy (Location)***

| | | | |
|---|---|---|---|
| Mean: | $668.84 | Median: | $626.95 |
| StErr: | $13.13 | | |

***Spread***

| | | | |
|---|---|---|---|
| StDev: | $928.18 | | |
| Max: | $3,263.30 | Q(.75): | $1,380.01 |
| Min: | ($1,289.66) | Q(.25): | ($79.24) |
| Range: | $4,552.97 | IQ Range: | $1,459.25 |

***Shape***

| | |
|---|---|
| Skewness: | 0.15156737 |
| Kurtosis: | -0.80965093 |

***Quantiles, Percentiles, Intervals***

| | 90% Interval | | 95% Interval |
|---|---|---|---|
| Q(.05): | ($762.74) | Q(.025): | ($902.38) |
| Q(.95): | $2,217.64 | Q(.975): | $2,454.71 |
| Alpha (α): | 0.05 | Q(α/2): | ($902.38) |
| % Interval: | 95% | Q(1-α/2): | $2,454.71 |

***Probabilities***

| | | | |
|---|---|---|---|
| | Pr( y > 0 ): | 73% | |
| Pr( y < | -700 | ) = | 6.35% |
| Pr( y > | 2000 | ) = | 8.67% |
| | | Pr( -700 < y < 2000 ) = | 84.98% |
| | | Alpha (α): | 0.1502 |

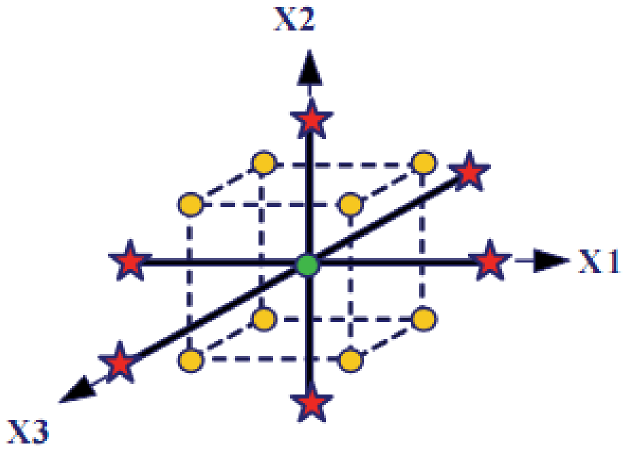
## *Example: Monte Carlo Results in Our MDO*

Stage 2

# Design of Experiment (DOE)

DOE is the step prior to the approximation approach which is often used to construct the RSM or neural network (NN) model.

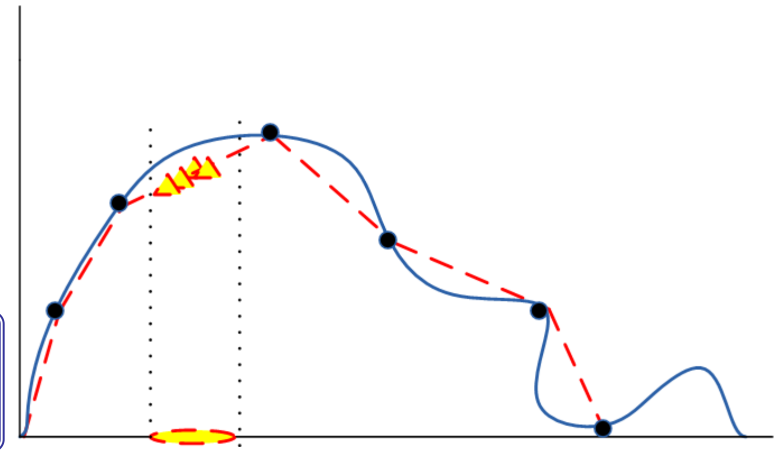
- Consider a simple problem; an optimized problem has 10 variables, and each variable has a possible range from 1-10. So the first question is that, when we conduct our optimization search, how small should the step size be to secure an acceptably good solution?




In our RSM process, we use Central Composite Design (CCD). CCD is a statistically based technique in which a 2-level full-factorial experiment is augmented with a center point and two additional points for each factor (called “star points”).

# Extended Research of Monte Carlo in MDO

- The random index is highly related to different simulation models
- The CI is related to the optimum level
- The distribution is important not only to the design space refinement, but also for the final results value.

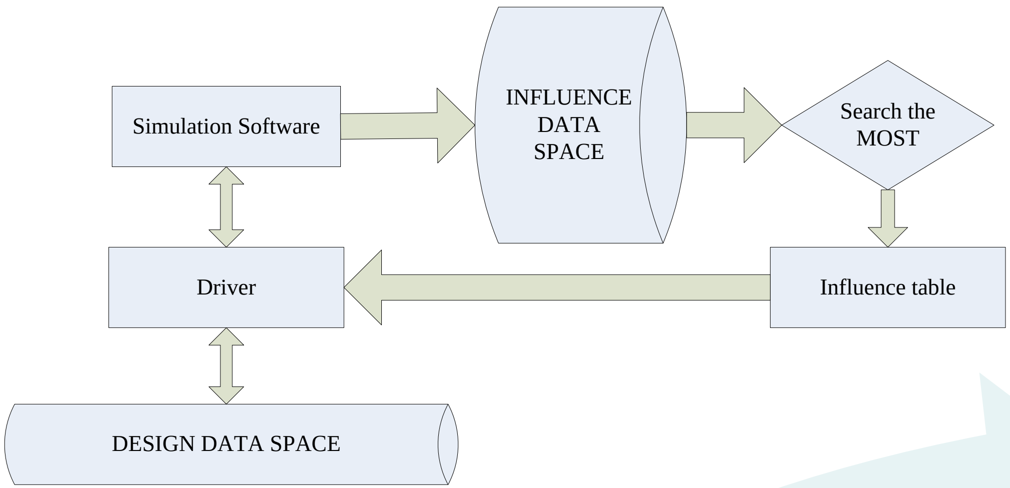


Question: if in one simulation, the results shows that the optimization goal is satisfied, when do I still need to repeat sampling and simulation according to the requirement of the Monte Carlo methods?

Answer: if the problem is a simple one, it is not necessary, but the real world is never so simple. the real engineering problem is often so complex that we only can use approximate models instead of real simulation models to conduct MDO.  In that case, the single results are not representative; only a distribution can give an useful clue to get the real solution, not the solution to the approximated models.

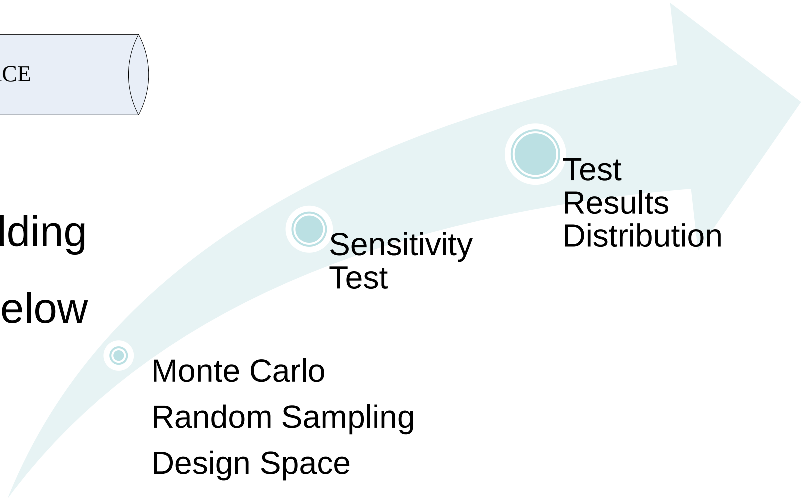
# Sensitivity test

Sensitivity Test is used to test which design variables are the most important ones and which can be ignored.




Non-linear combination requires adding

Monte Carlo process, as showed below



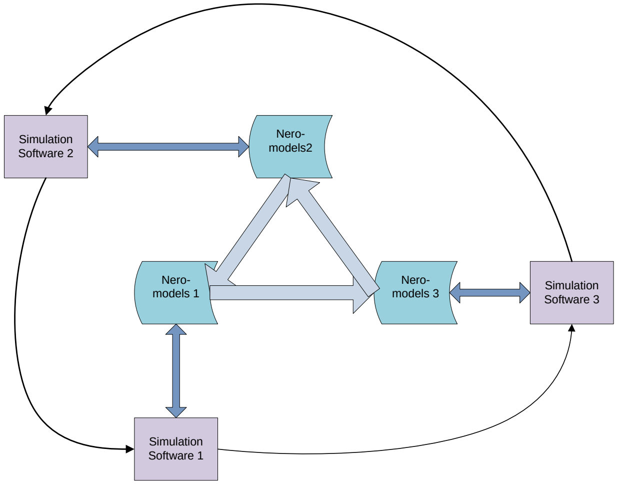
# Approximation Methods--Neural Network

There is no universally accepted definition of an NN. But perhaps most people in the field would agree that an NN is :

- A network of many simple processors ("units"), each possibly having a small amount of local memory.
- Units are connected by communication channels ("connections") which usually carry numeric (as opposed to symbolic) data, encoded by any of various means.
- Units operate only on their local data and on the inputs they receive via the connections. The restriction to local operations is often relaxed during training.

# Using Neural-Network in MDO

We are using incorporating a Neural-Network in our MDO research



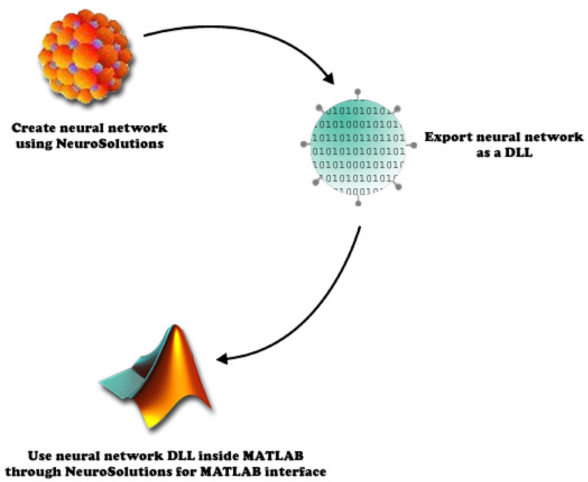

- To reduce the simulation time, a well trained Neural network can be substituted for the original simulation model

- Use the simulation results to train a Neural Model

- Use the Monte Carlo Sample to distribution the Neural Points

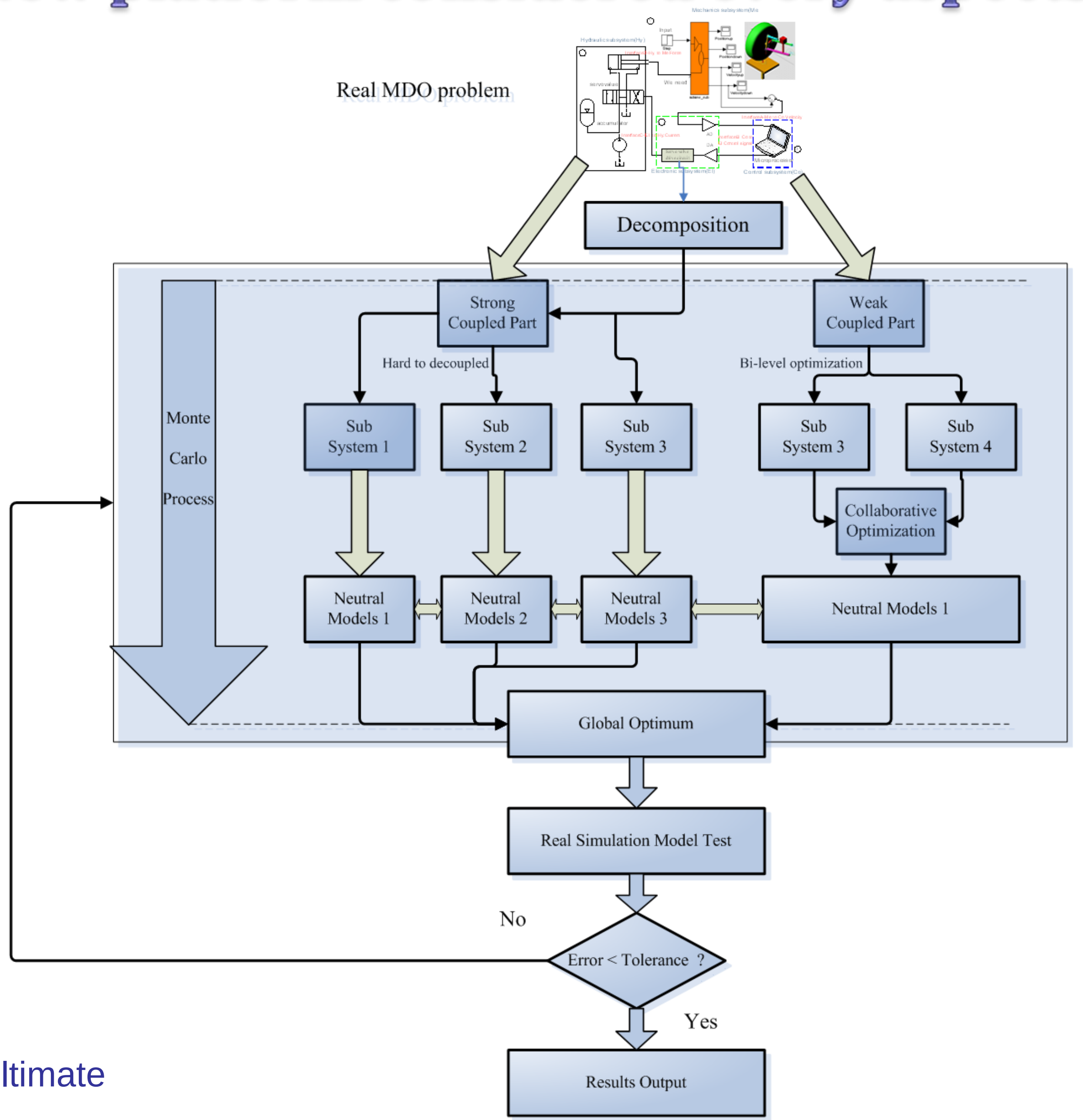
- Use known points to test trained Network

- Use Approximate Sub-models to communicate among each other




Stage 3

# New platform considered every aspects




Stage Ultimate

# Conclusions

Before we conclude, let's recall the disadvantage of MDO----

- ***Complex coupled situation***

  Solved by the CO & Integrated Simulation Method

- ***Time and Resource Consuming***

  Solved by the design space refinement and approximate models methods (Neural-solution)

- ***Hard to get the global optimization results***

  A local optimum is still an improvement and can be a good solution

Besides, the confidence interval of the optimization results can be predicted, and the accuracy of the prediction can be calculated

# Question and Comments?

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