Reliability and DOE

- What is reliability?
- What is DOE?
  - definition
  - process
  - tools
- How do they relate?

Reliability is...

- **Field which**
  - **predicts future product failure rates**
  - **prioritizes areas for design attention**
  - **estimates the amount of development testing required to reduce failures to targeted rate**
    - **test, analyze and fix**
    - **reliability growth curves**

What industries are represented here?

DOE is...

- **Design of Experiments**
  - **an efficient technique to collect an adequate amount of usable data with the least amount of effort**
  - **can be used with hardware or computer simulations**

Who has previous exposure to DOE?

DOE Definition

- **DOE organizes the collection of development test data to determine the most statistically confident relationship between inputs and outputs.**
  - **Complexity of the relationship is chosen by the user.**

Provides understanding
- equation
- priority
- area of interest

UDLP Projects

- Interior ballistics model, live gun firings, adhesives for stub case and for sleeve, compulsator, propellant temp. sensitivity
- Analytical foundations, curved beam equilibriater, drive sizing, accuracy, control optimization, cannon thermal, recoil
- Mk 45 seal, Mk 45 computer screens, VLS canister opening & activation, electrical cable, Crusader crew module, VLS tapping, sleeve gun drilling, steel casting chemistry, LP compatability, weld distortion, mechanisms
- Mech eng. cost estimating, VLS flyout

6 of these projects saved an estimated $183,000

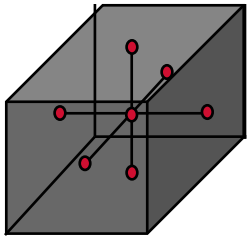
St. Thomas Projects

- Welding, web processes
- Molding plastic and rubber (gaskets, diaphragms and piece parts)
- Adhesive in assembly, epoxy curative reaction, powder coating colorization
- Plating, vapor deposition
- Laser cutting and surface grinding equipment
- Medical fluid sampling equipment
- Sealing repeatability, product durability
- Office process flow, process waste
- Analysis of hydraulic, thermal & molding

13 of these projects saved an estimated $700,000

DOE vs. Traditional Methods

- **Traditional Methods come in two forms:**
  - **The benefit of DOE over Traditional will be shown after definitions are provided**
- **The first approach: One Factor At a Time(OFAT)**
  - **Fix all variables and only changes one of them to understand its effect.**
  - **Then they fix it at the "best" level, and change another variable. This is continued until all variables are completed or funding expires.**
  - **Each step occurs one at a time - thus this is also called One Factor At a Time (OFAT) testing.**
  - **The direct affect of each variable can be determined but the interaction between variables is not available.**



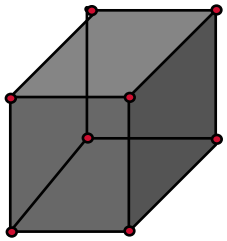
DOE vs. Traditional Methods (cont.)

- **Second approach**
  - **Change many things at the same time. If the problem gets fixed, it is hard to tell which variable did it. Thus all are considered important. Not an organized or systematic approach.**
  - **Other words for these traditional approaches are: by guess / by golly, hit and miss, seat of the pants, "shotgun approach, or more nicely "Exploratory Testing".**

How well does this describe what you have typically seen???

DOE vs. Traditional Methods (cont.)

- **DOE changes variables in a structured, predetermined manner.**
  - **The number of variables to explore and the form of the output equation desired is traded off with the budget and schedule constraints on the project.**
  - **Statistical analysis is performed on the test results to ensure the final equation is valid, accurate and predictable.**



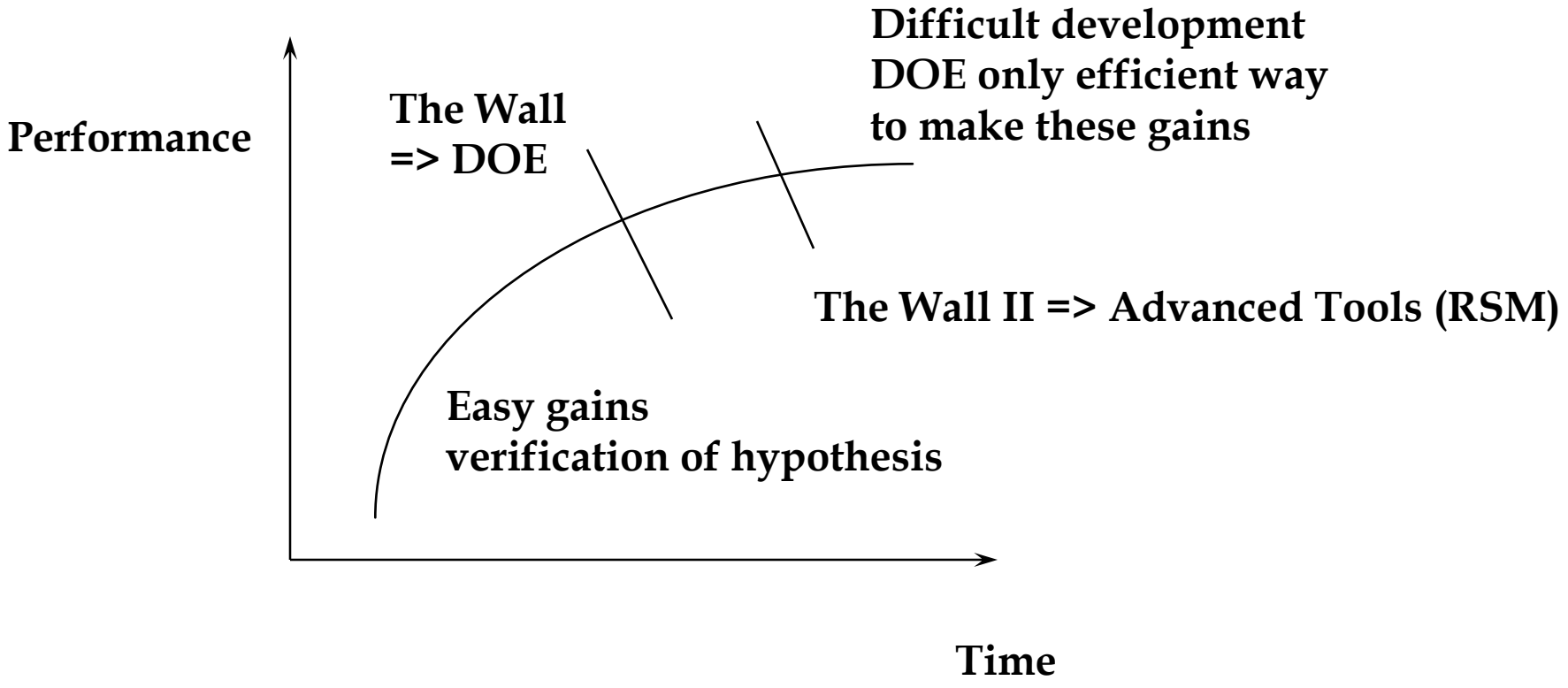
Benefit of DOE vs Traditional Methods

- **OFAT for 3 variables gives 16-24 tests**
- **DOE for 3 variables gives 8 tests for a 50%-67% savings in cost and schedule.**

DOE (Classical) and Taguchi

- Taguchi makes assumptions for use in the electronics industry which simplify the mathematics. This does not carry over well to other fields.
- His philosophy about “robust design” is good but is not unique. Some tools which support his “robust design” philosophy and some DOE tools are questionable.
- DOE is not Taguchi but Taguchi is a subset of DOE

Design Stages



DOE Process

- Define goal - need
- Define response(s) to measure progress to goal
- List all variables and down select to “key” variables using engineering judgment
- Select appropriate design matrix - approach *
- Select safe/consistent test levels for variables
- Address tradeoffs between responses
- Perform test
- Analyze results *
- Discuss next step

* Where DOE software helps

Tools

- **Factorial Designs**
  - **Full (2^k form)**
  - **Fractional (2^{k-p} form)**
  - **Taguchi - maximum assumptions**

Organizing the collection of data to determine the most statistically confident relationship

- **Advanced Designs (Response Surface Methods)**
  - **3 level (<u>not</u> a 3^k form)**
  - **5 level (composite with factorial as a basis)**
  - **Optimization**
- **Related Statistical Tools**
  - **Probabilistic Failure Assessment (PFA)**
    - **New use of old tools (Monte Carlo analysis)**
  - **Statistical Process Control (SPC)**

Tool Comparison / Typical Equations

OFAT or Taguchi typical output (main effects)

$$y = z + a*A + b*B + c*C$$

More information (fine tuning) is achieved as progress to more rigorous tools

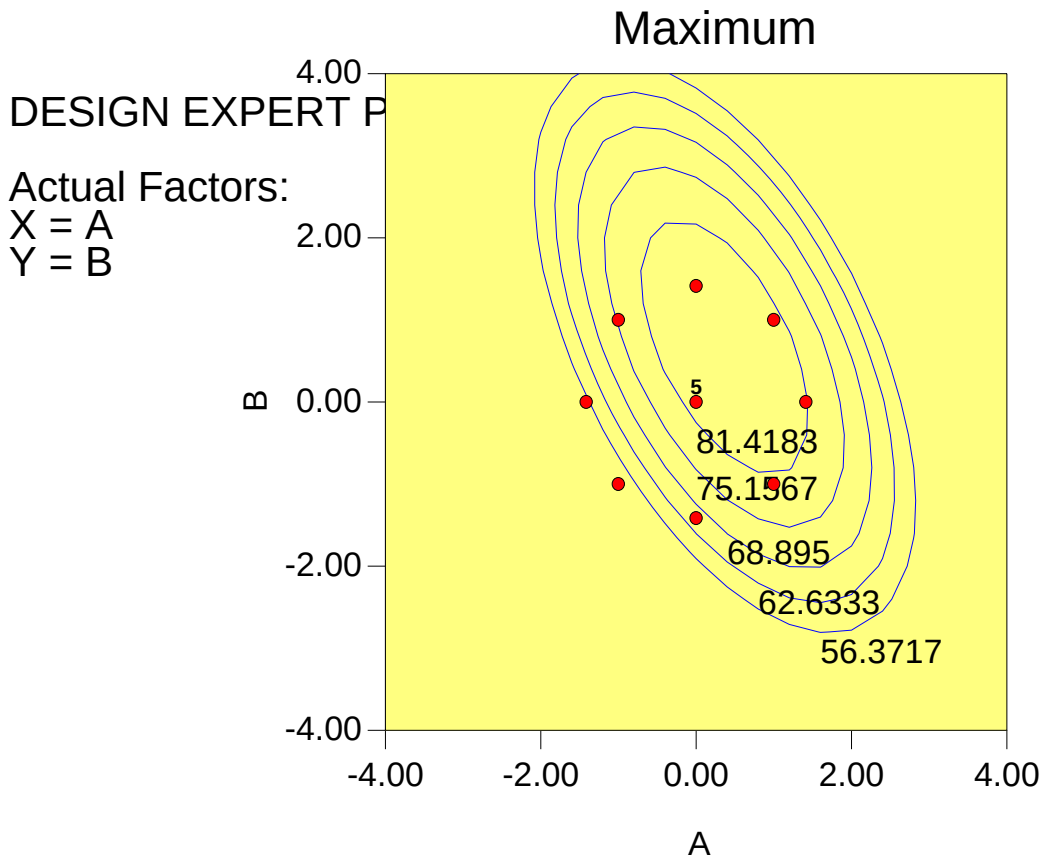
Factorial typical output (main and interactions)

$$y = z + a*A + b*B + c*C + d*A*B + e*A*C + f*B*C + g*A*B*C$$

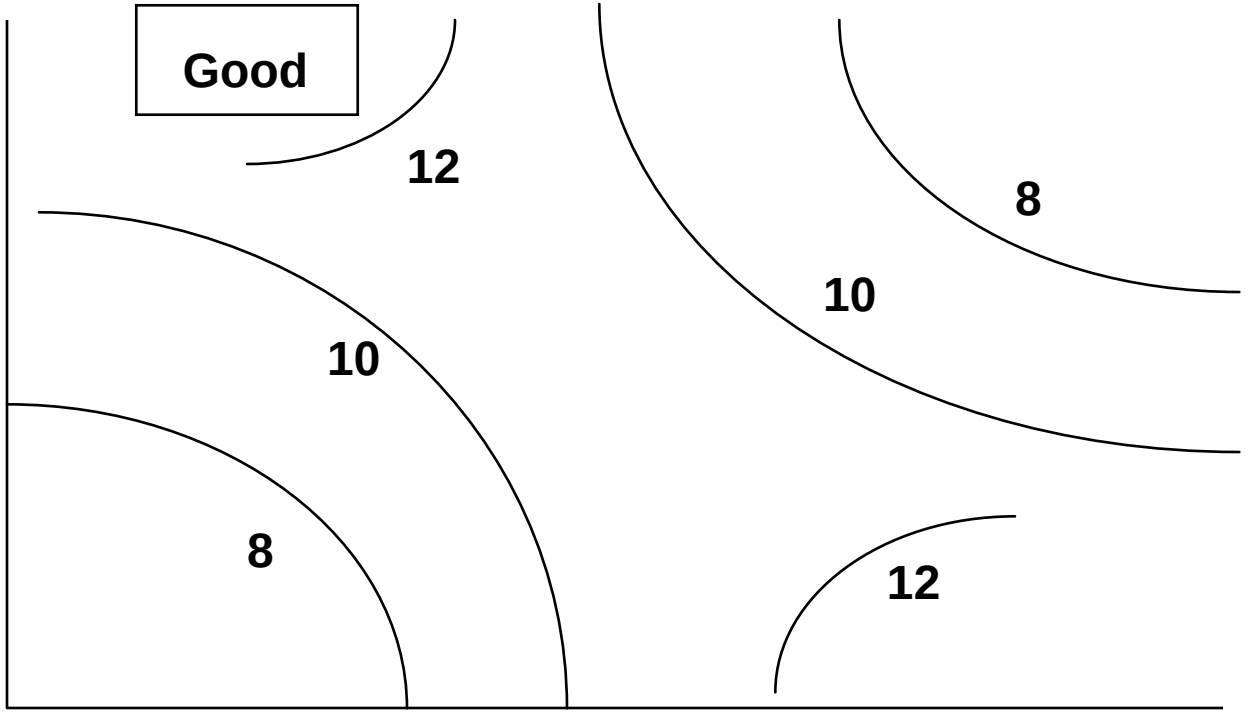
Response Surface typical output (main, interactions, quadratic)

$$y = z + a*A + b*B + c*C + d[A]^2 + e[B]^2 + f[C]^2 + g[AB] + h[AC] + i[BC] + j[ABC] + p[A]^3 + q[B]^3 + r[C]^3 + s[A^2B] + t[AB^2] + u[A^2C] + v[AC^2] + w[B^2C] + x[BC^2]$$

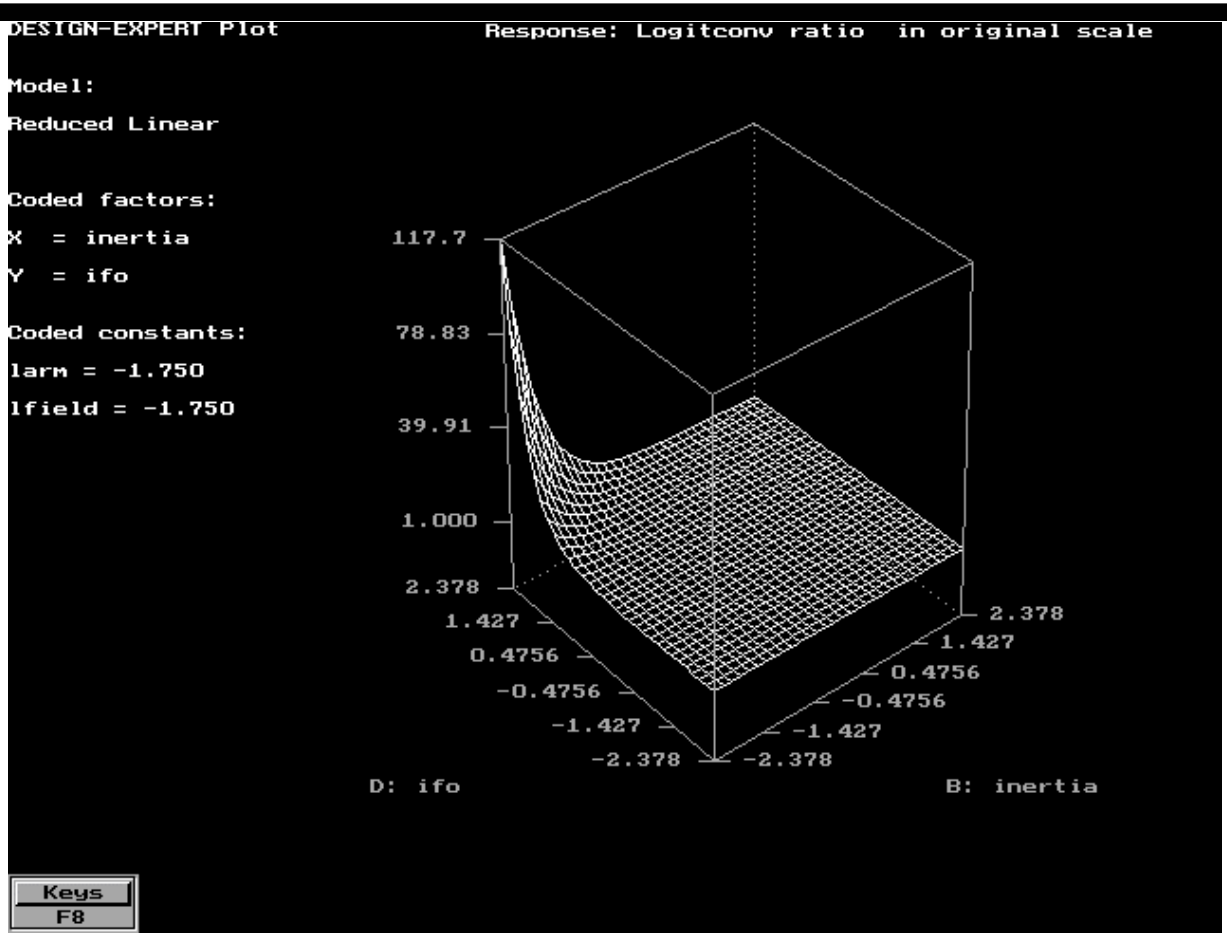
Maximum, 2-D


Maximum
DESIGN EXPERT P
Actual Factors:
X = A
Y = B
4.00
2.00
0.00
-2.00
-4.00
B
-4.00
-2.00
0.00
2.00
4.00
A
5
81.4183
75.1567
68.895
62.6333
56.3717

RSM, Postage Stamp

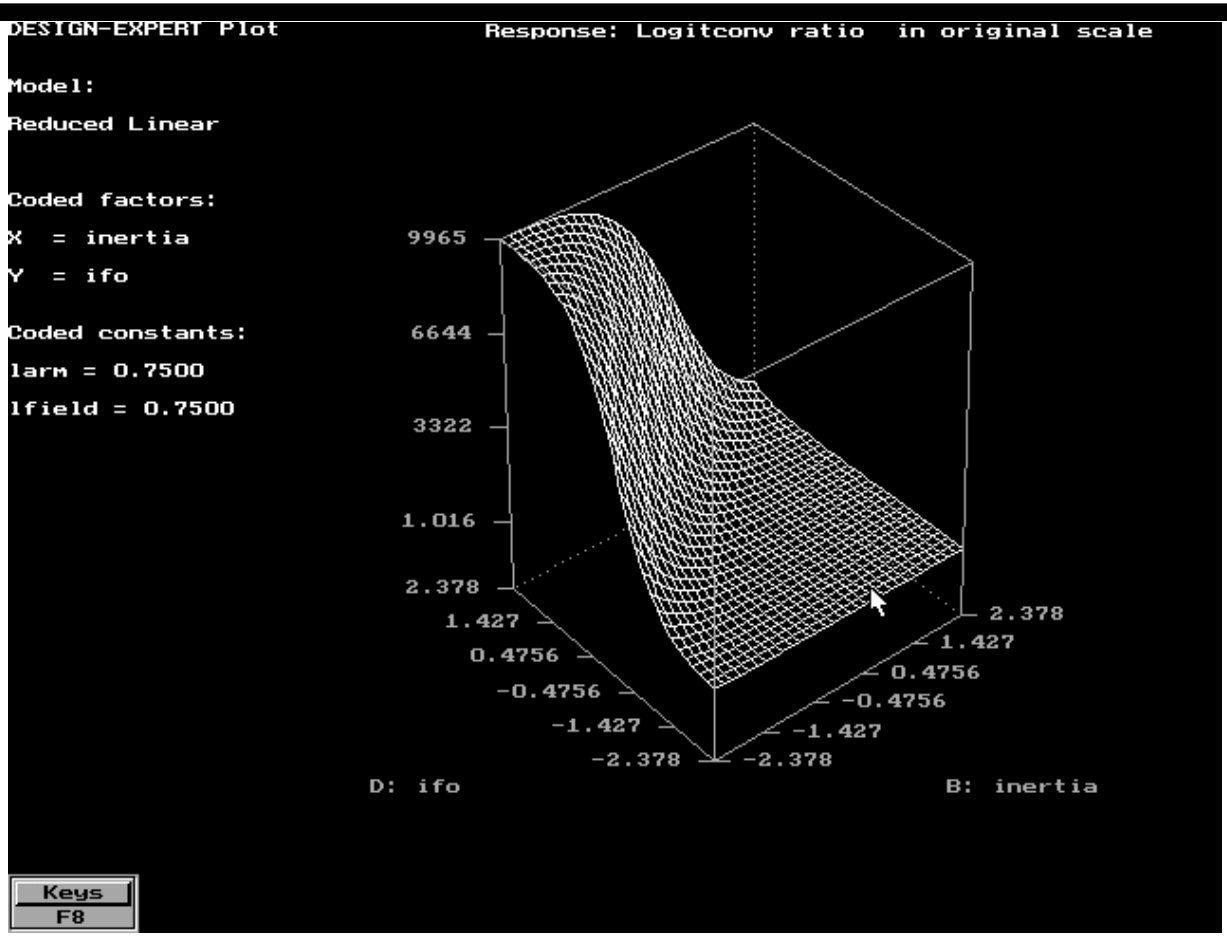


RSM Profile



Quick transition from flat to vertical. Sensitive design space.

RSM Profile



A more gradual transition from flat to vertical. More stable design space.

Reliability and DOE Relationship

- DOE can be used to improve reliability of products
- Variance as a response in testing
- Also by improved process capability
- If design has a variable in a flat spot, with wear the performance will not change much
- Rotating machinery is a tough area for reliability, which is common to ASD
- Probabilistic Failure Analysis Tool

Probabilistic Failure Analysis

- Technique to reduce number of hardware tests to determine failure rates.
- Develops an empirical model based on existing data and physical understanding
- Uses Monte Carlo analysis to determine failure rate and improve design
- “Fly the first product” ability
- Also known as Probabilistic Design Analysis

Summary

- **Reliability and DOE can fit together well**
- **Reliability Engineers can be the catalyst to influence the development process to a more efficient pattern**

DOE Software Checklist

- Should include diagnostics
- Should include center point option
- Allowance for transformations
- Allowance for botched data
- Allowance for foldover
- Nice if it allows for customized randomization
- User to consider future RSM needs, ability to transfer existing files into RSM software

Reference Books

- Box, Hunter and Hunter - “Statistics for Experimenters” ISBN 0-471-09315-7
- Box and Draper - “Empirical Model Building and Response Surfaces” ISBN 0-471-81033-9
- Diamond - “Practical Experiment Designs for Engineers”
- Ross - “Taguchi Techniques for Quality Engineering” ISBN 0-07-053866-2
- Cornell - “How to Run Mixture Experiment for Product Quality” ISBN 0-87389-021-3

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