A Numerical Solver for the National Cycle Program

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NCP
National Cycle Program

- The NCP is a NASA/Industry Cooperative Effort to build a common system modeling capability for aerospace propulsion systems.
  - *General Electric Aircraft Engines (Cincinnati)*
  - *Pratt & Whitney (East Hartford, CT)*
  - *Boeing (Seattle, WA)*
  - *Allied Signal (Pheonix, AZ)*
  - *Arnold Engineering Development Center. (TN)*

- The NCP Solver is designed to solve 0-D to 1-D system simulation problems.
  - Physical systems are decomposed into discrete elements (inlet, compressor, burner, etc.).
  - Elements are connected in a network.
  - NCP Solver manages execution of elements and data flow between them.
  - The level of detail in each element can vary (from data tables through full 3D models) but at the system level, everything is 1-D.

NCP Solver Flexibility

- The NCP is more flexible than most commercially available simulation codes, which were designed primarily for controls design.
- Any model input parameter can be controlled by the Solver in order to achieve a desired goal.
- The NCP solver can handle any problem that can be phrased as

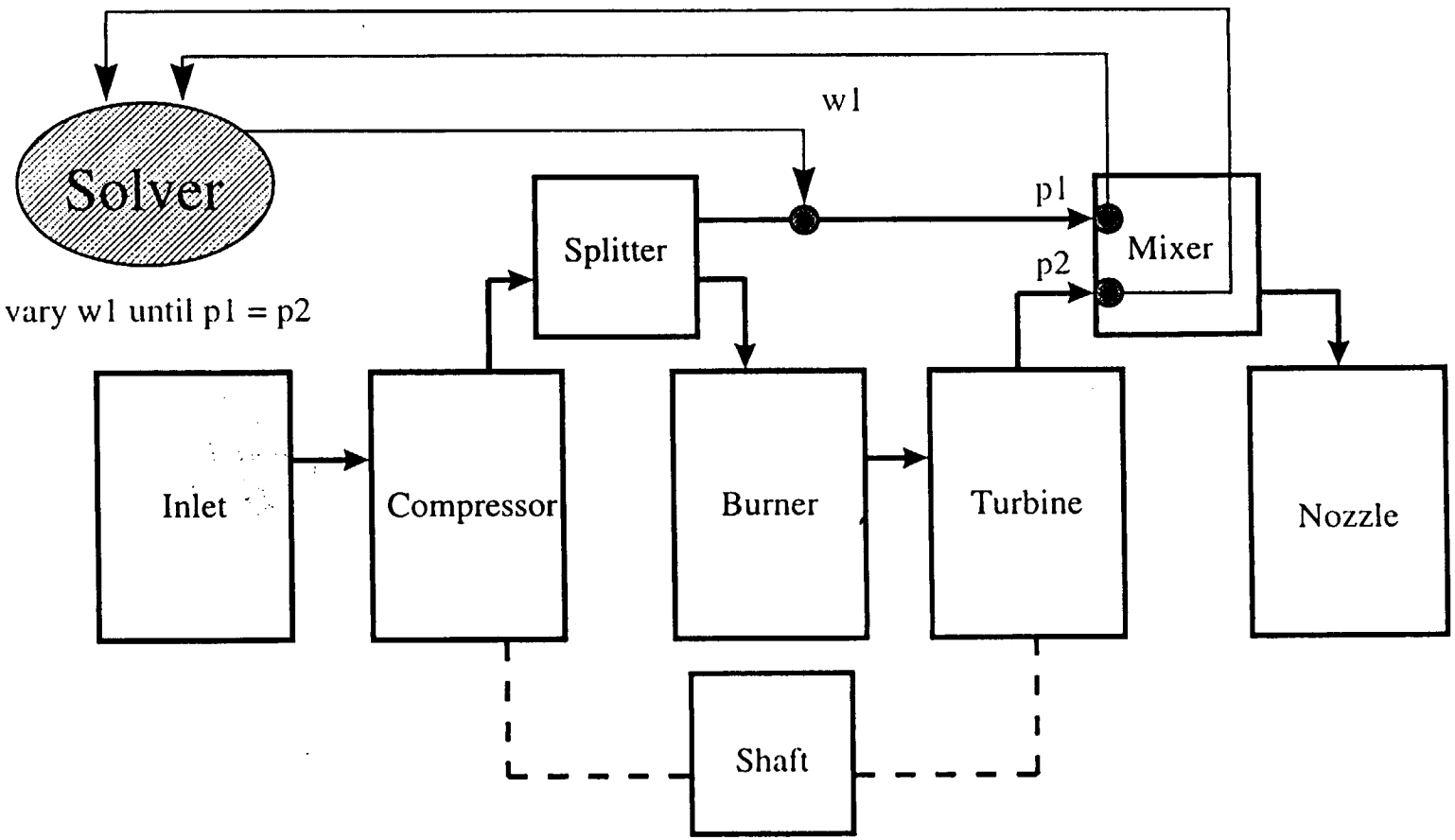
$$\textbf{vary } x_1 \textbf{ until } a_1 = b_1$$

- There can be more than one parameter x controlling an equal number of balances between a and b.

$$\textbf{vary } \{x_1, x_2, \ldots x_n\} \textbf{ until } \{(a_1=b_1) \,\&\, (a_2 = b_2) \,\&\, \ldots \,\&\, (a_n = b_n)\}$$

NCP

Analysis | Design | Data Reduction | Transient | Constraints



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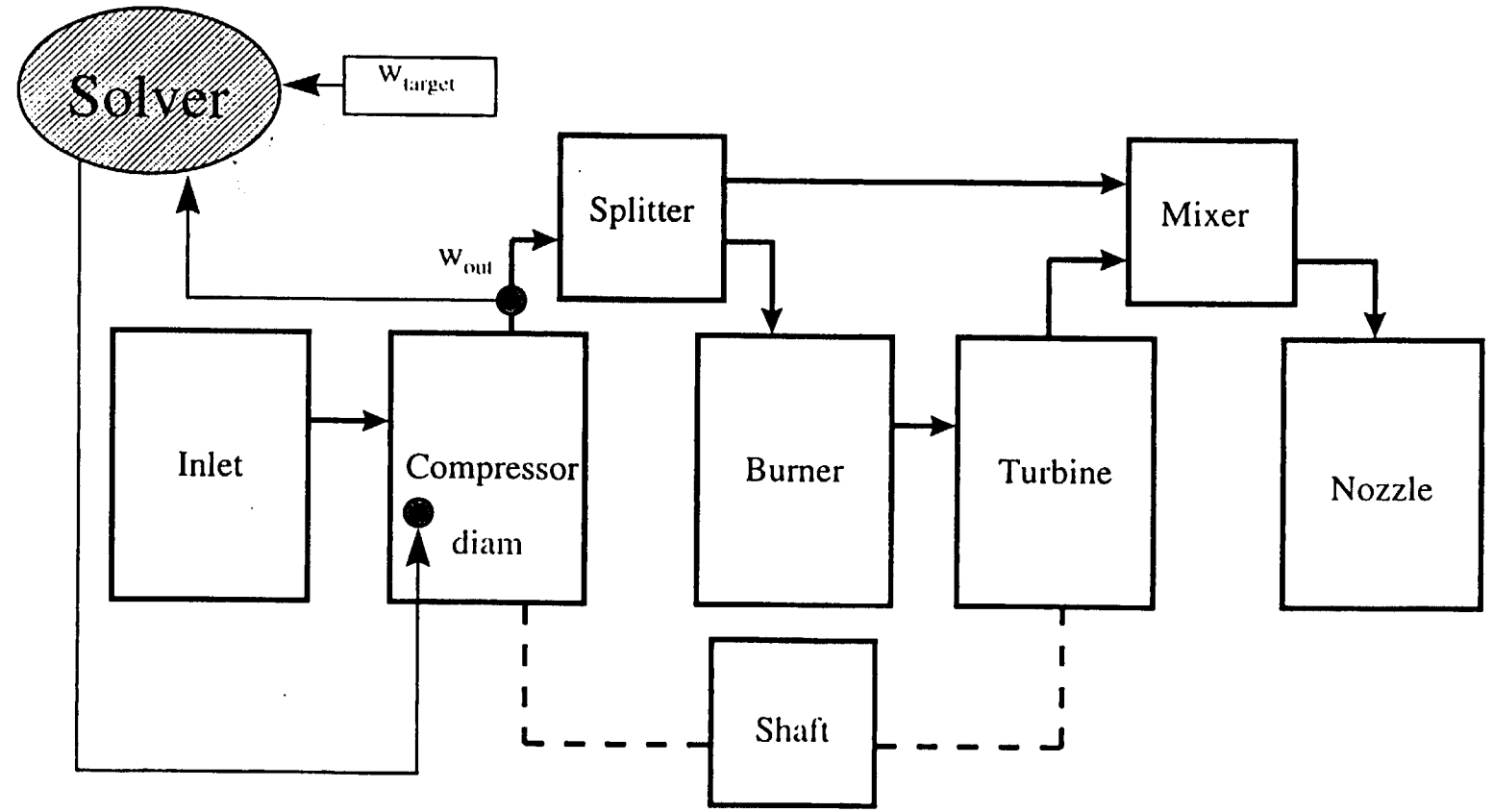
Analysis

NCP

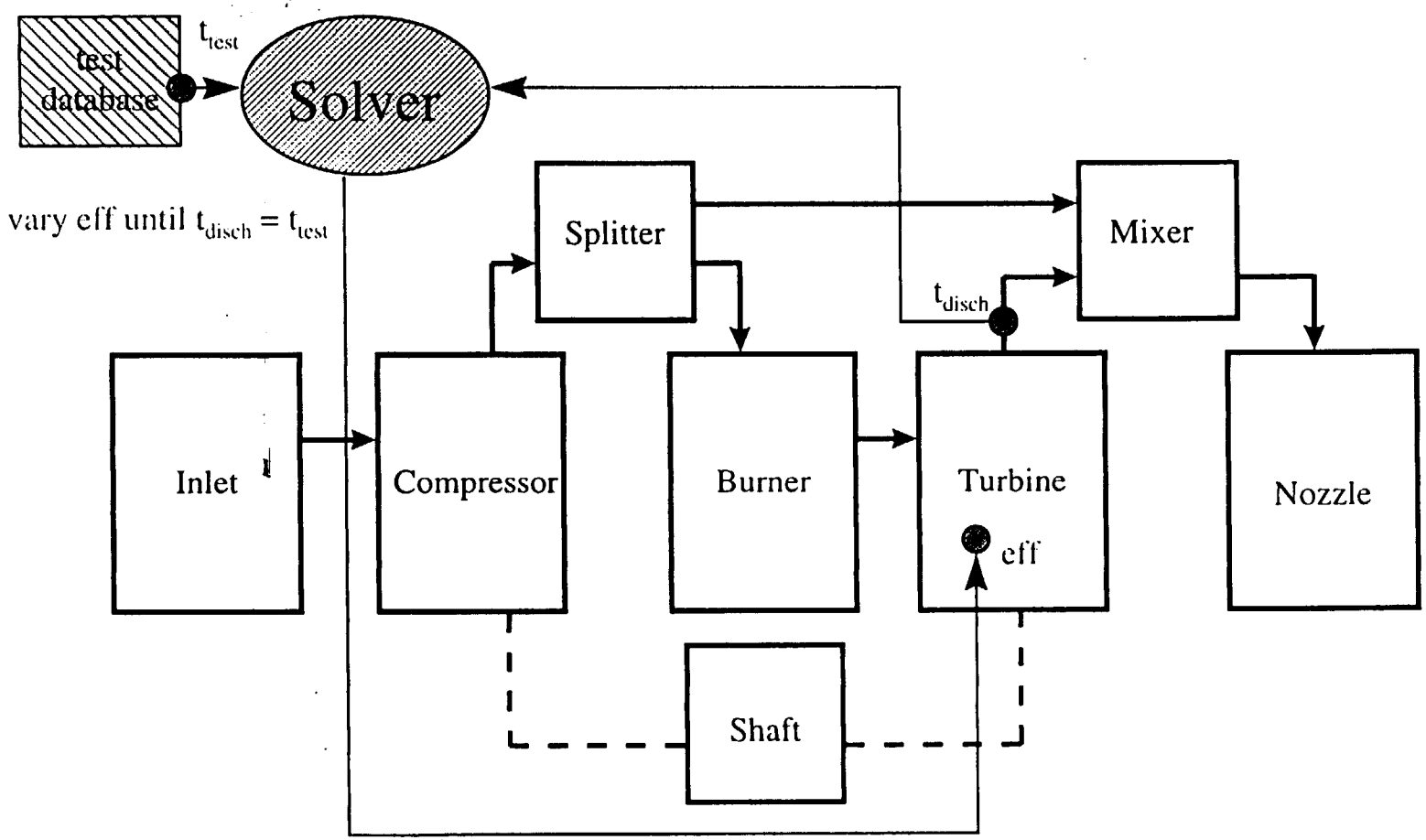
Analysis | Design | Data Reduction | Transient | Constraints

vary diam until $w_{out} = w_{target}$



NCP

Analysis | Design | Data Reduction | Transient | Constraints



NCP

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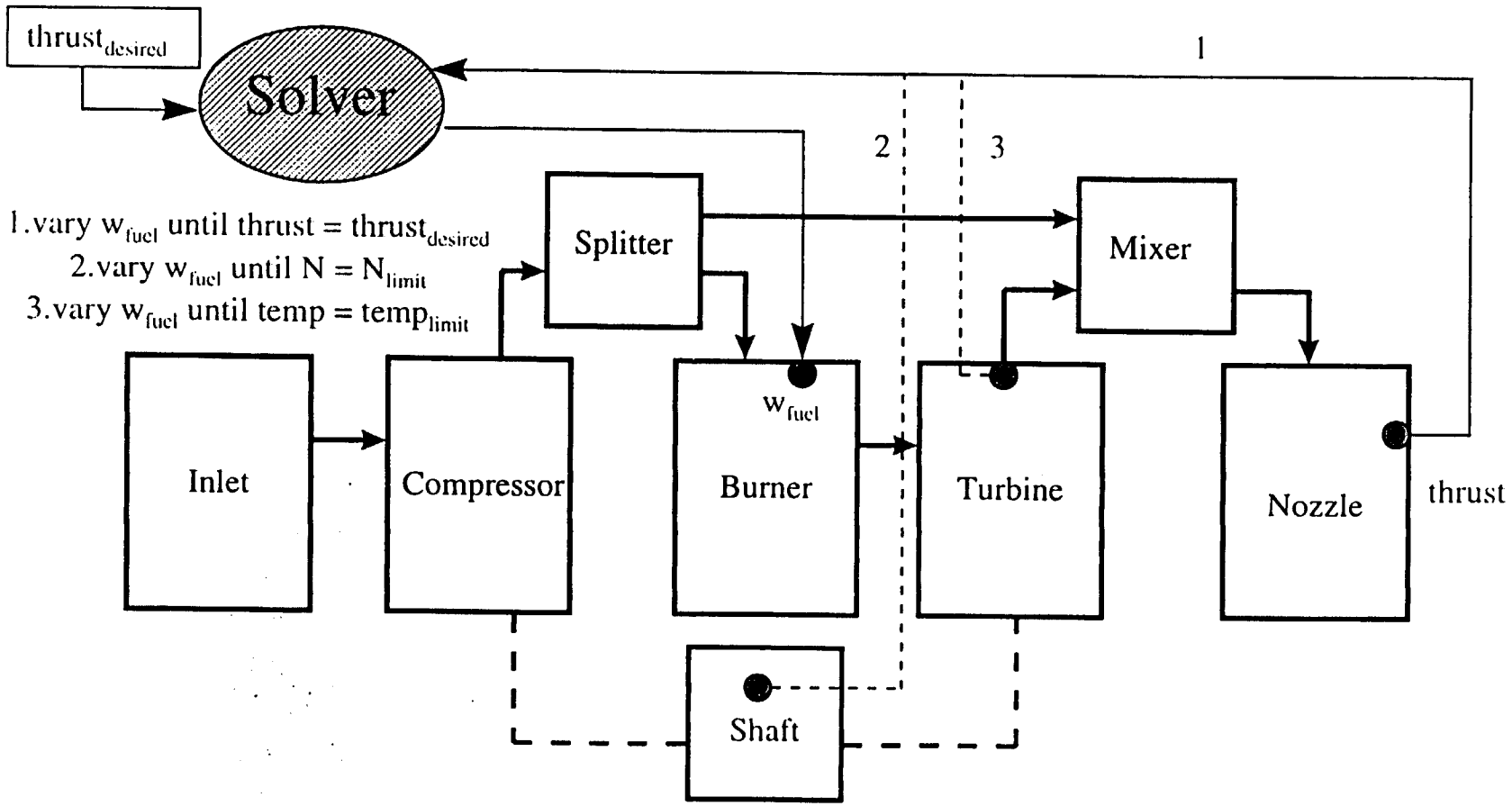
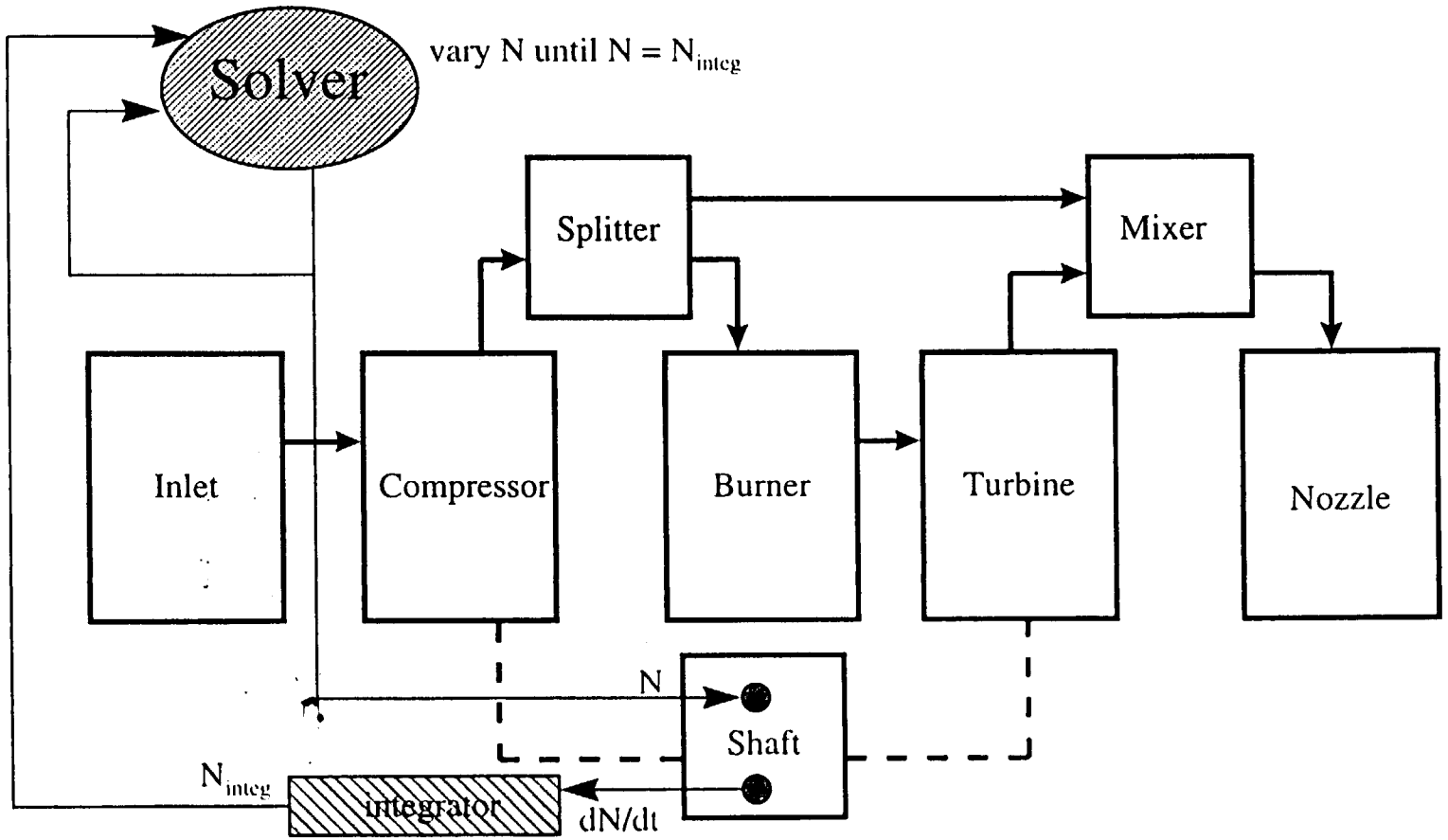


Constraints

NCP

Analysis | Design | Data Reduction | Transient | Constaints



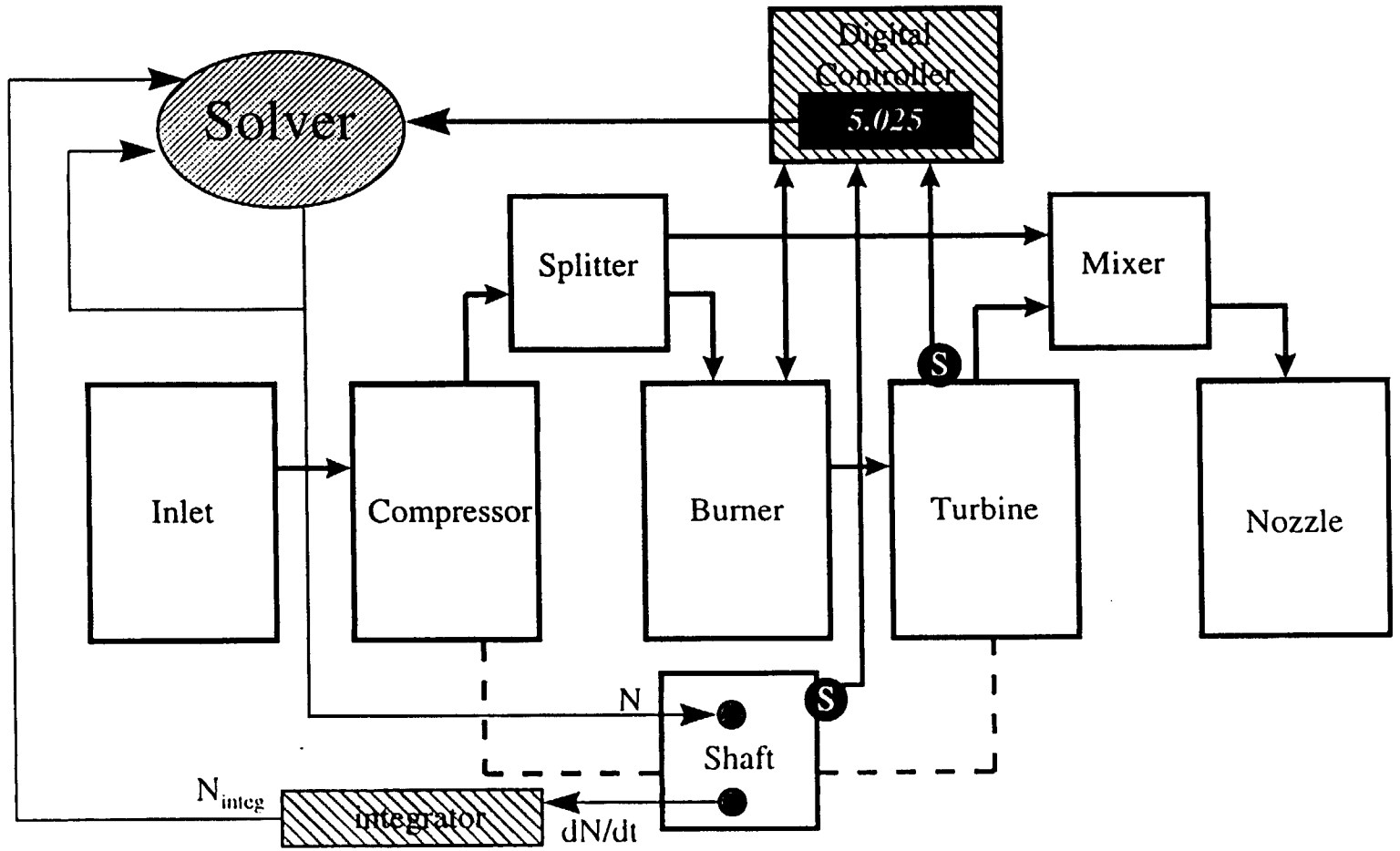
Time-Dependent

Special Transient Mode Functions

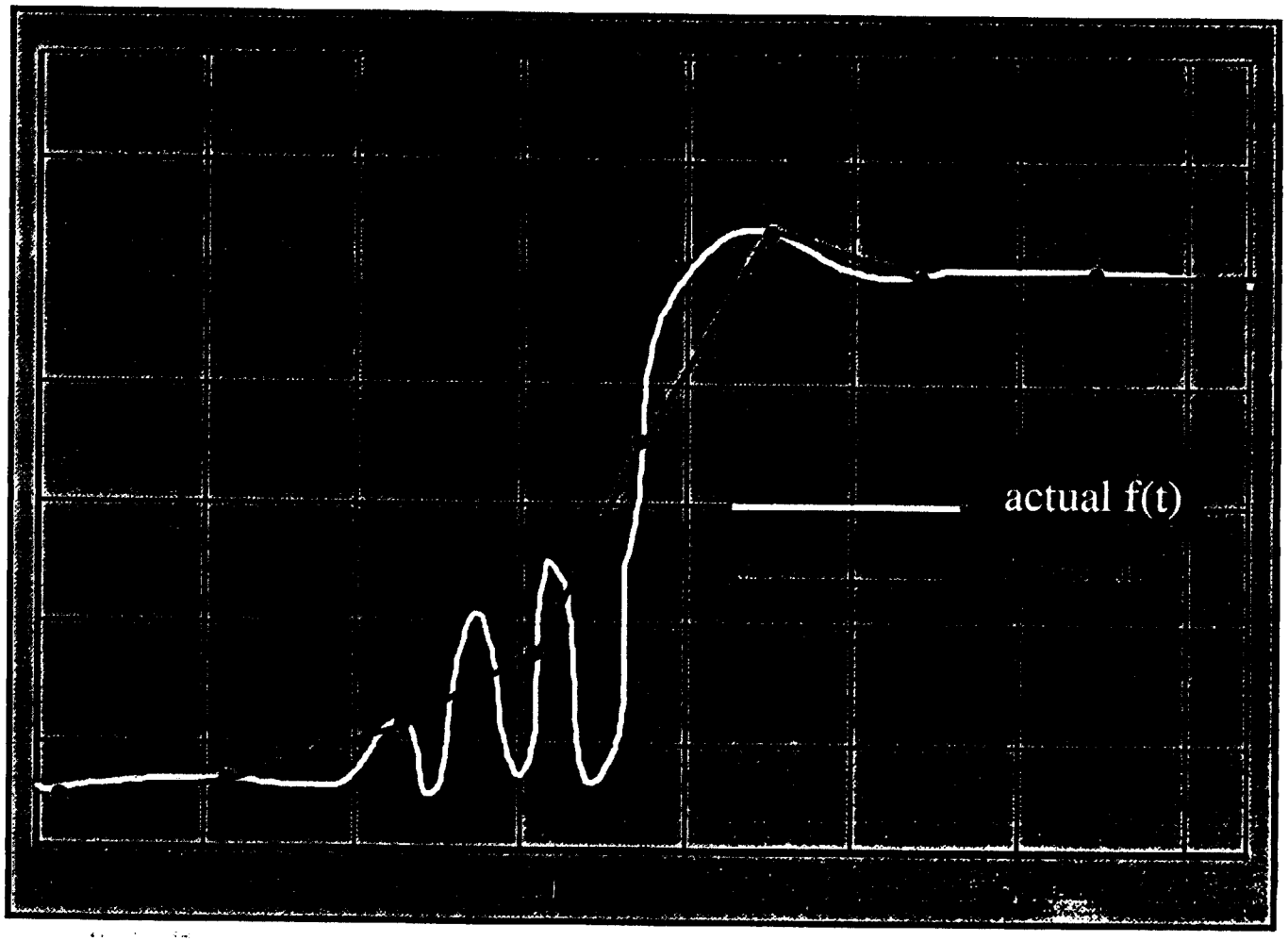
- Synchronization with Digital Control Elements
- Adaptive time-step (dt) computation

NCP Time-Discrete Synchronization

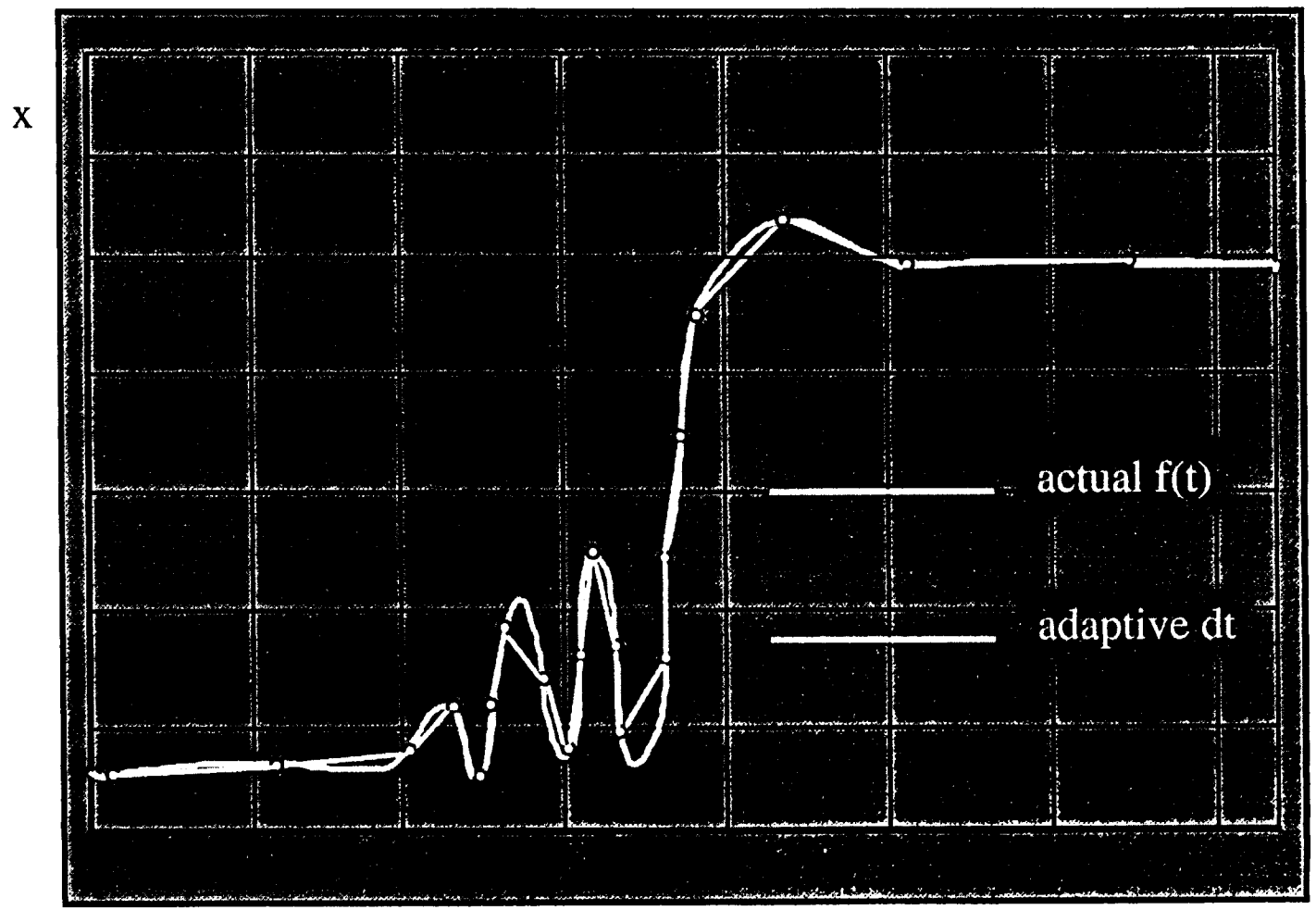
Analysis | Design | Data Reduction | Transient | Constraints



Adaptive Time-Stepping



Adaptive Time-Stepping



Basic Solution Methodology

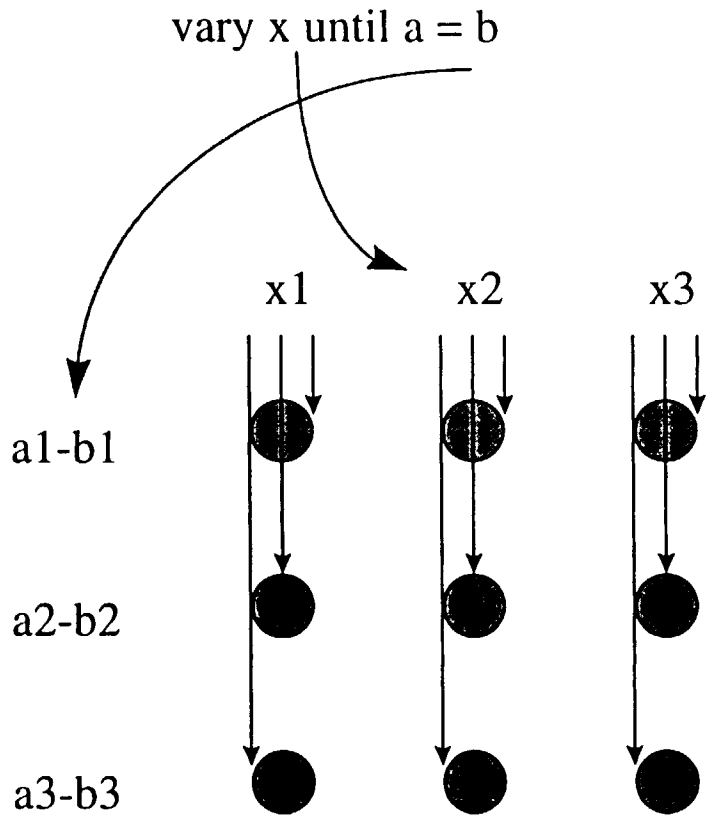
- **Provides a valid physical solution at each steady-state point or transient time-step.**
- **Uses a Modified Newton-Raphson technique**
  - ***Generates matrix of partial derivatives called the Jacobian***

$$J_{ij} = \partial(a-b)_i \Big/ \partial(x)_j$$

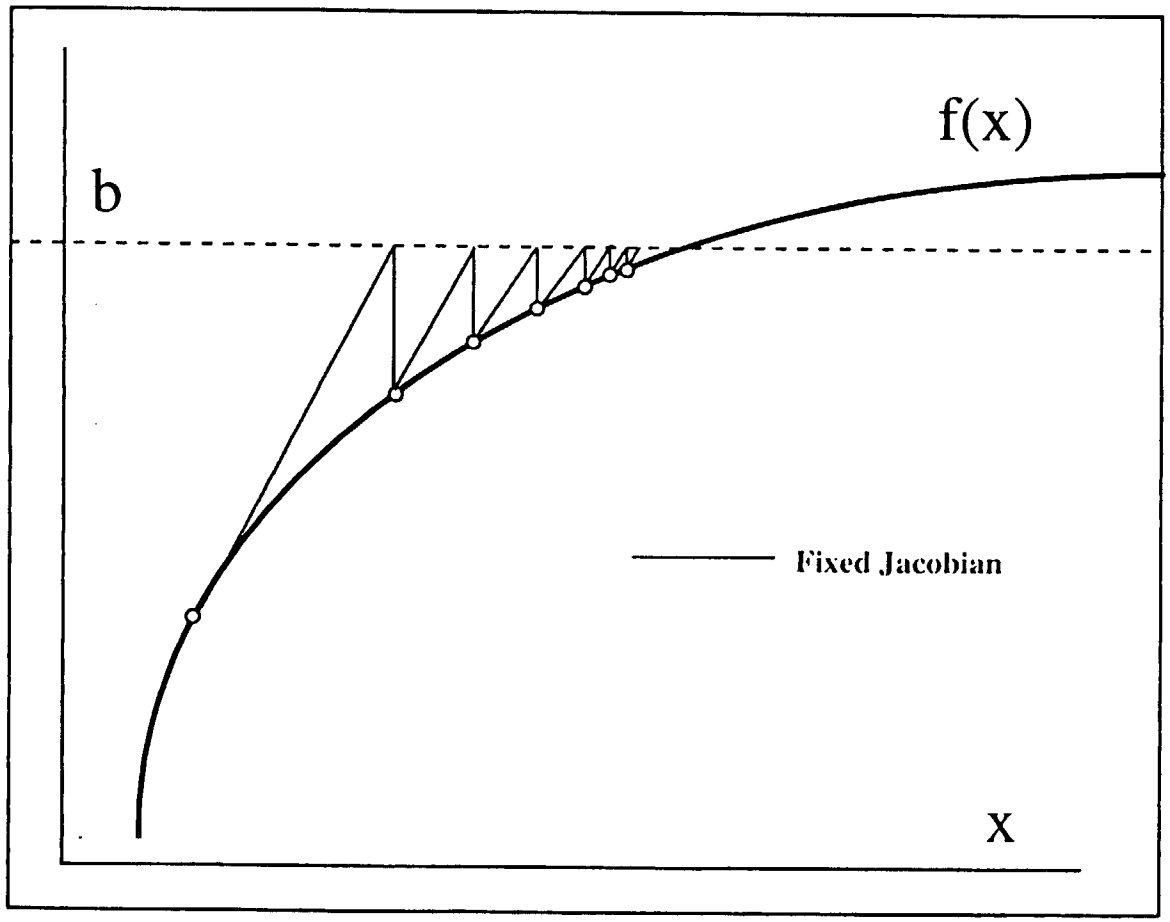
  - ***Inverts the matrix to compute x values that will drive errors (a-b) to zero.***
  - ***Modifies J and J^{-1} to account for changes in slope during convergence process.***
  - ***Limits the allowed change in x per iteration in order to prevent divergence.***

Creating the Jacobian Matrix

$$J_{ij} = \partial(a-b)_i / \partial(x)_j$$

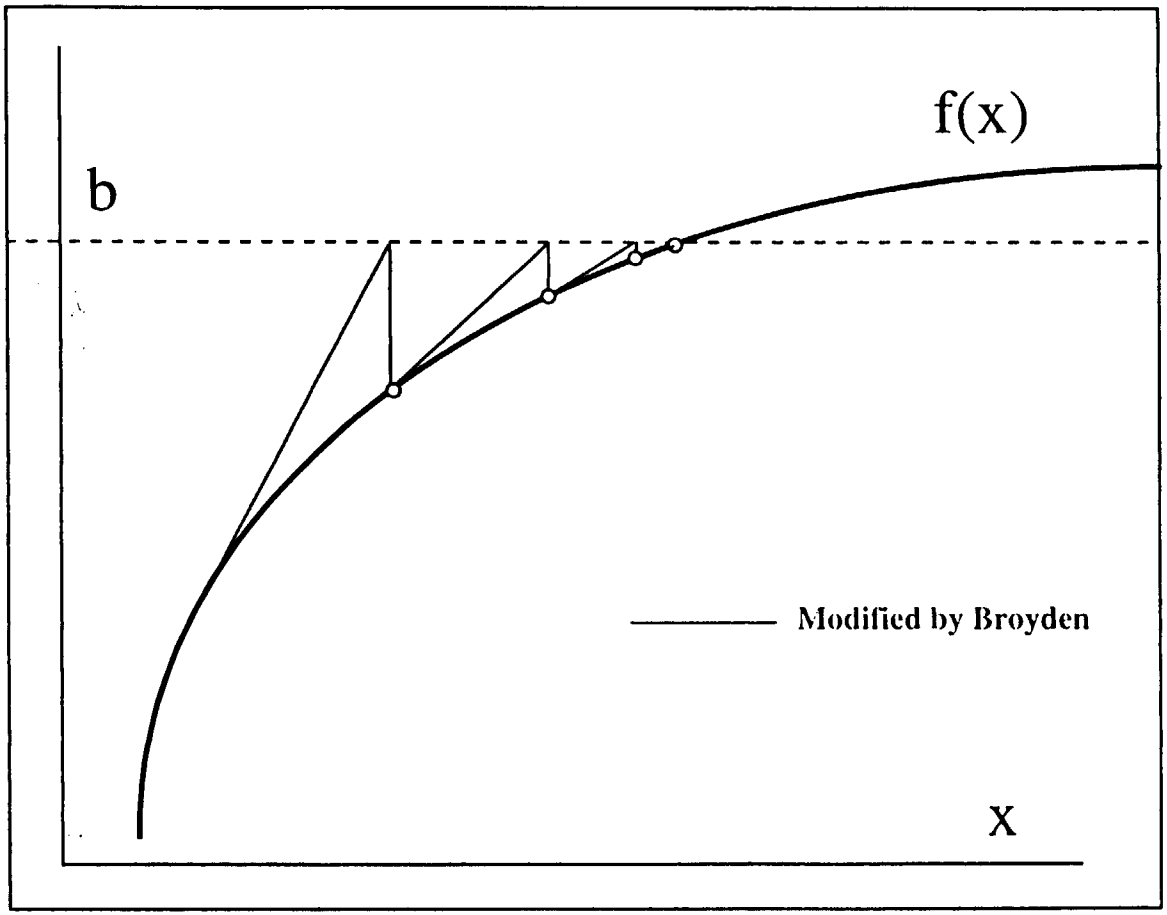


Modified Newton-Raphson Method



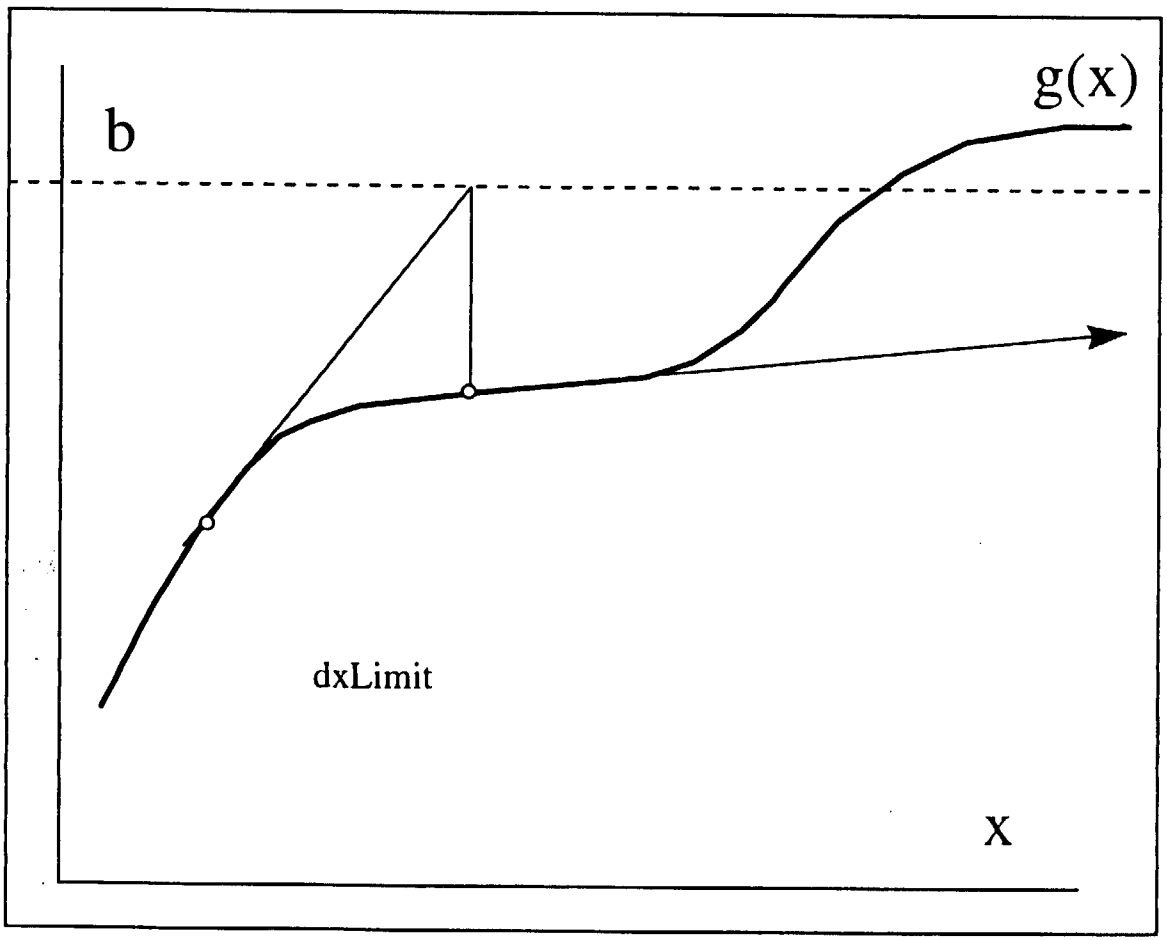
vary x until f(x) = b

Modified Newton-Raphson Method



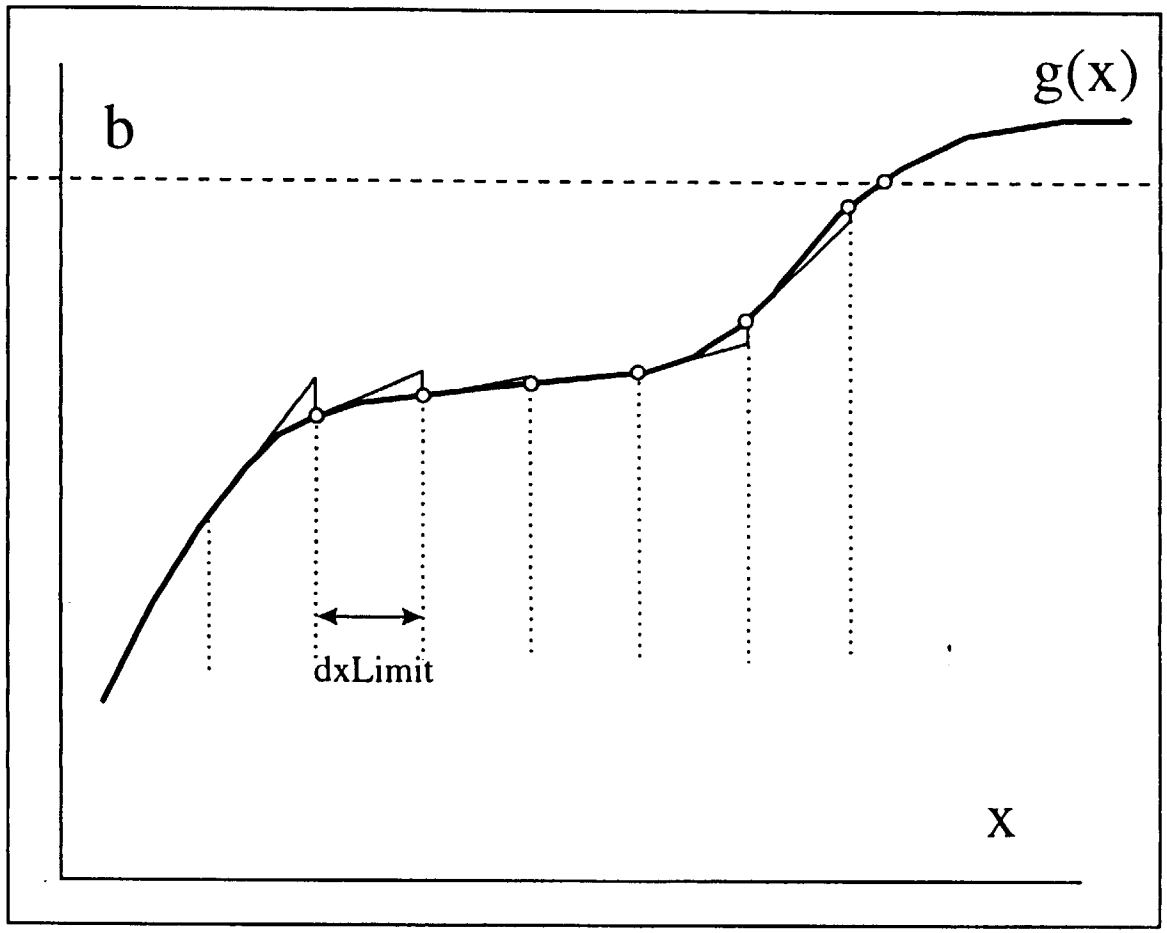
vary x until f(x) = b

Stiff Systems and dx-limiting



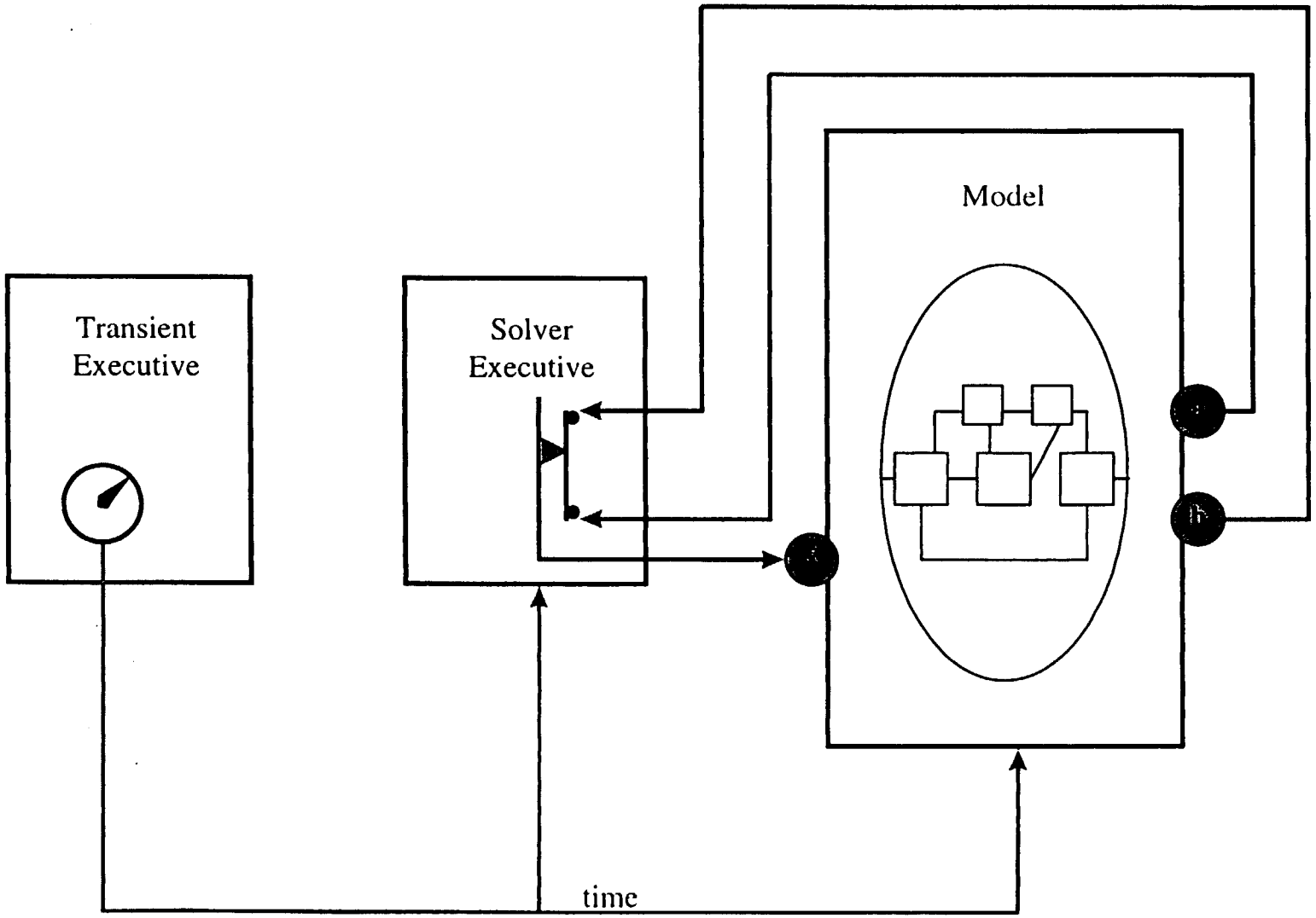
vary x until g(x) = b

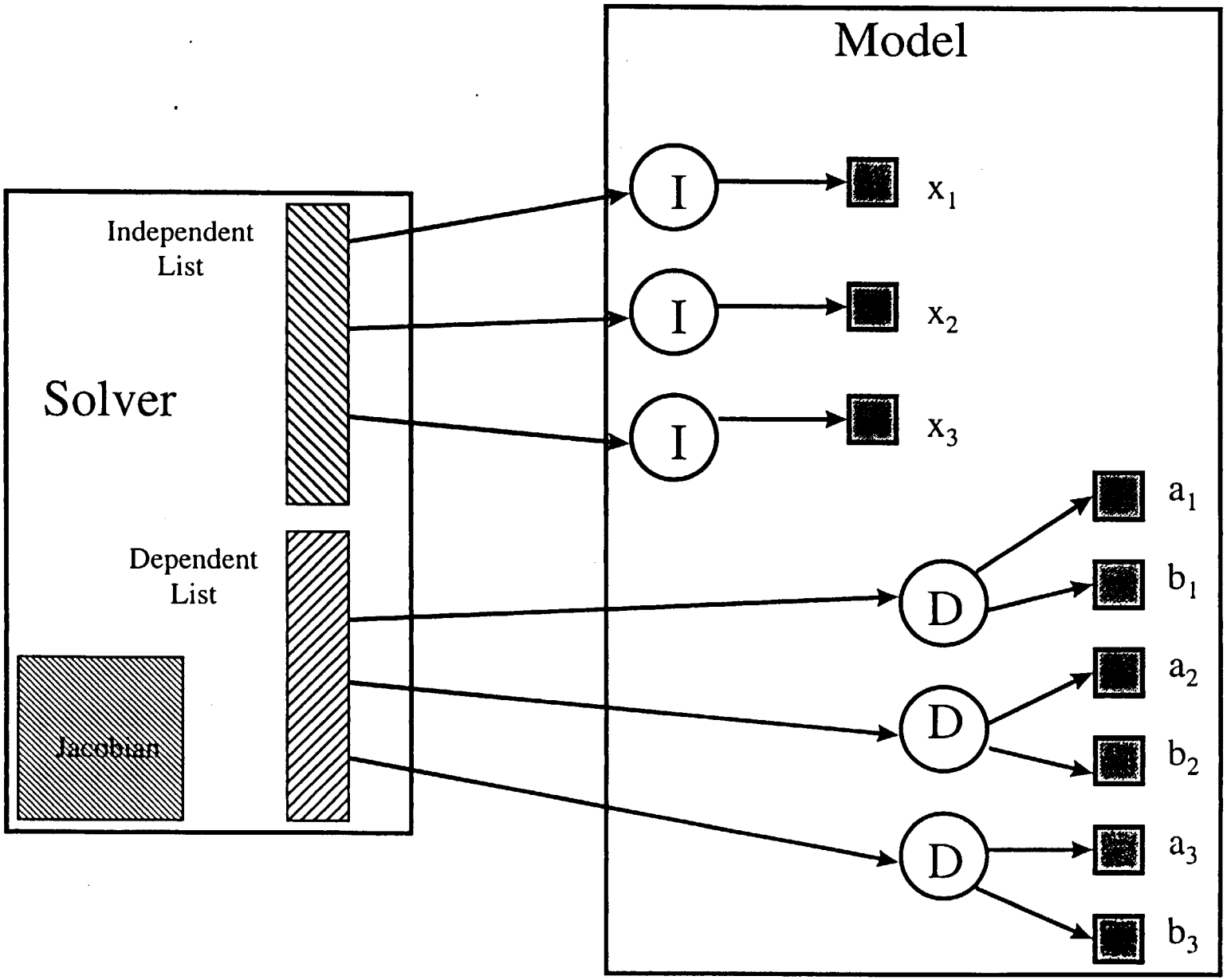
Stiff Systems and dx-limiting



vary x until g(x) = b

Solver Design




Model
Solver
Independent List
Dependent List
Jacobian
I
I
I
D
D
D
x_1
x_2
x_3
a_1
b_1
a_2
b_2
a_3
b_3

Summary

•The NCP Solver provides a great deal of versatility for system modeling of aerospace propulsion systems.

- Analysis
- Design
- Data Reduction
- Constraints
- Transients

•The Solver user a robust solution method with an established track-record (in system modeling and finite-difference analysis).

•The Solver Subsystem has a modular, object-oriented architecture which enhances the overall flexibility and maintainability of the NCP software.