Structural Optimization and MDO in Industry

by
Johannes Schweiger
EADS-Deutschland
Military Aircraft

RTA-AVT-86 Technical Course
METU, Ankara, 25 – 29 March 2002

Content

- Typical design impacts from Aeroelasticity
- Stimulation for the development of analytical optimization tools
- Basic functions and features of tools
- LAGRANGE as an example
- Application examples
- MDO in the aircraft design process
- The role of MDO for Active Aeroelastic Structures

Typical aeroelastic and structural dynamic impacts on fighter aircraft

- Dynamic:
- Flutter (multiple external store configurations)
- Buffeting (dynamic loads on wings and vertical tails)
- Coupling effects between structure and flight control system
- Performance of sensor systems, installation of equipment
- Static:
- Impacts on manoeuvrability (mainly roll and yaw)
- Impacts on static stability
- Aileron reversal, control surface hinge moments
- Aerodynamic load redistribution

Typical aeroelastic and structural dynamic impacts -some examples-

- Flight envelope limitation for multiple store configurations, especially with variable wing sweep (TORNADO, F-14, F-111)
- Flutter balance mass in transport aircraft wings (n*100 kg)
- Roll performance (F-18 redesigns)
- Vertical tail buffeting (F-18, TORNADO)
- Wing buffeting (F-15)
- Coupling with FCS (F-22, Gripen)
- Aerodynamic performance of flexible wing (Airbus A-340)
- Qualification levels for vibration of equipment
- Performance of sensor system

Flutter Incident after “minor” modifications

Structural optimization in Aeronautics

Stimulations

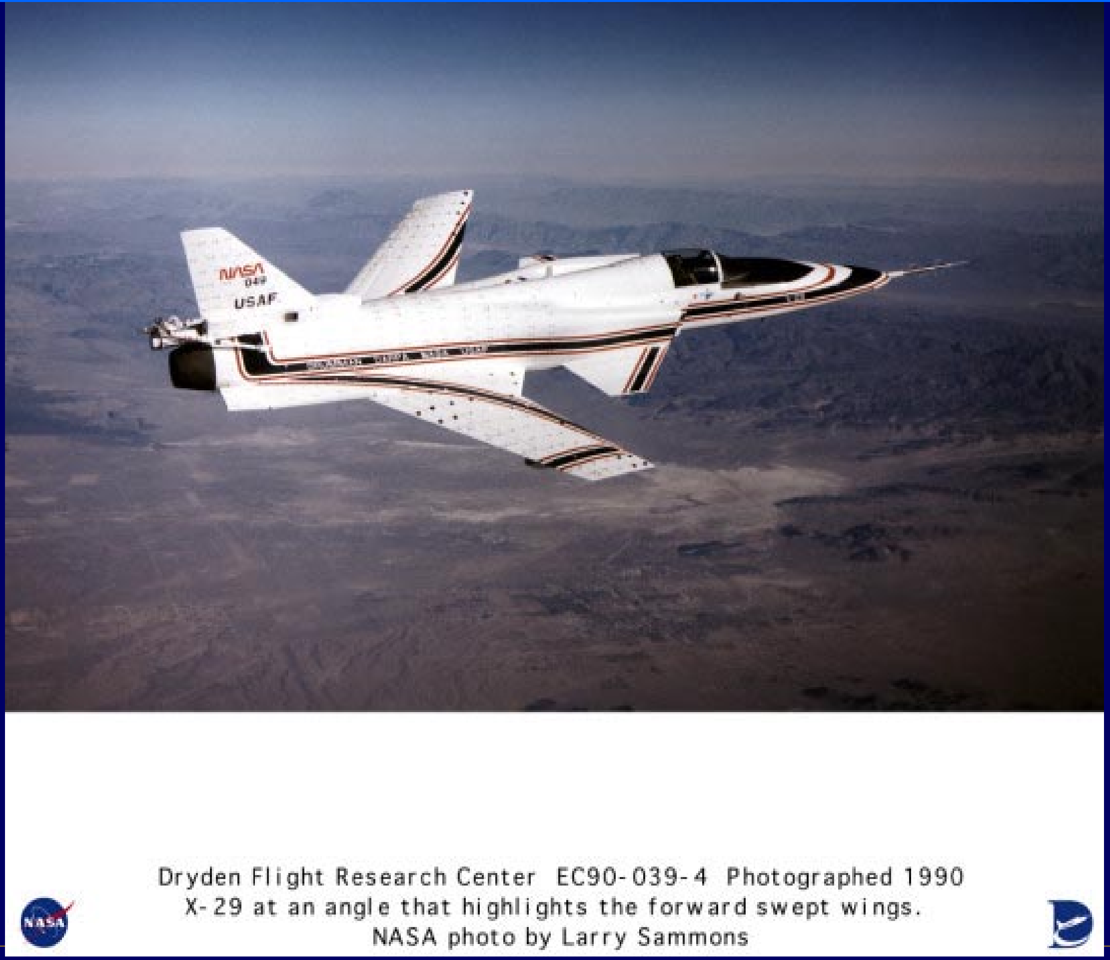
- Formal optimization algorithms are almost mandatory to improve the aeroelastic characteristics of a design by modified stiffness distributions.
- Anisotropic material properties of high-elastic-modulus composite materials enlarges the design space.
- Increased computing power allows more refined structural models (FEM).
- Increased aircraft performance results in more severe aeroelastic impacts on the design.

Aeroelastic Tailoring - Definitions

- *Aeroelastic Tailoring...refers to a design process in which minimum weight is an ever present objective.*
- *...equally important, [it] involves the use of structural deformation of a lifting surface to achieve aircraft performance objectives not usually associated with structural design.*
- *The effectiveness ... relies upon the creation of external aerodynamic loads through controlled deformation.*
- *Aeroelastic Tailoring is the embodiment of directional stiffness into an aircraft structural design to control aeroelastic deformation, static or dynamic, in such a fashion as to affect the aerodynamic and structural performance of that aircraft in a beneficial way.*

Quoted from "*A Survey of Aeroelastic Tailoring - Theory,Practice, Promise*"
by M. H. Shirk, T. J. Hertz, T. A. Weisshaar. AIAA-84-0982-CP

An Example for Aeroelastic Tailoring
Structural Divergence of Forward Swept Wings



Dryden Flight Research Center EC90-039-4 Photographed 1990
X-29 at an angle that highlights the forward swept wings.
NASA photo by Larry Sammons

Levels of Aeroelastic Tailoring

- Passive
- Stiffness distribution (material thickness, arrangement of parts)
- Creative use of directional, anisotropic stiffness characteristics
- Positioning and shape of aerodynamic control surfaces
- Shape of main surface
- Active
- Use aerodynamic control surfaces as tabs to deflect main surface
- Adaptive use of multiple control surfaces
- Active materials and active structures concepts

Aeroelastic Tailoring - Prerequisites -

- Reliable analysis methods
- Suitable analysis models
- Efficient formal optimization methods
- Simultaneous multidisciplinary optimization
- Knowledge of material properties
- Establishment of design criteria (failure criteria)
- Evaluation of “best” manufacturing concepts and processes
- Exploitation of material potential in design optimization

Major Steps at EADS-D

- 1978: Need for formal optimization methods
  w. r. t. aeroelasticity for new project and CFC
- 1979: FASTOP programme
- 1980: “Weisshaar method” for Aeroelastic Tailoring
- 1983: TSO programme
- 1984: Start of LAGRANGE development
- 1985: Wing shape optimization (TSO)
- 1986: WT test for tailored vertical tail
- 1990: Tape laying feature for curved fibers
- 1995: Begin of Active Aeroelastic Structures research
- 1996: MDO project (EC, Brite Euram)
- 1997: Tow steering options
- 1998: Fluid - Structure coupling for CFD methods
- 2000: EC MDO project MOB (Blended Wing Body)
- 2001: EC project 3AS

FASTOP - Flutter and Strength Optimization Program

- Developed under US Air Force Contract by Grumman
- FEM for wing structures
- Fully Stress Design (optimality criterium)
- Sequential optimization for flutter
- Variables : element thickness, lumped masses
- Composite materials: only with constant, anisotropic material properties per element

- Features added at Dasa:
  - Static aeroelasticity
  - Buckling stability

TSO

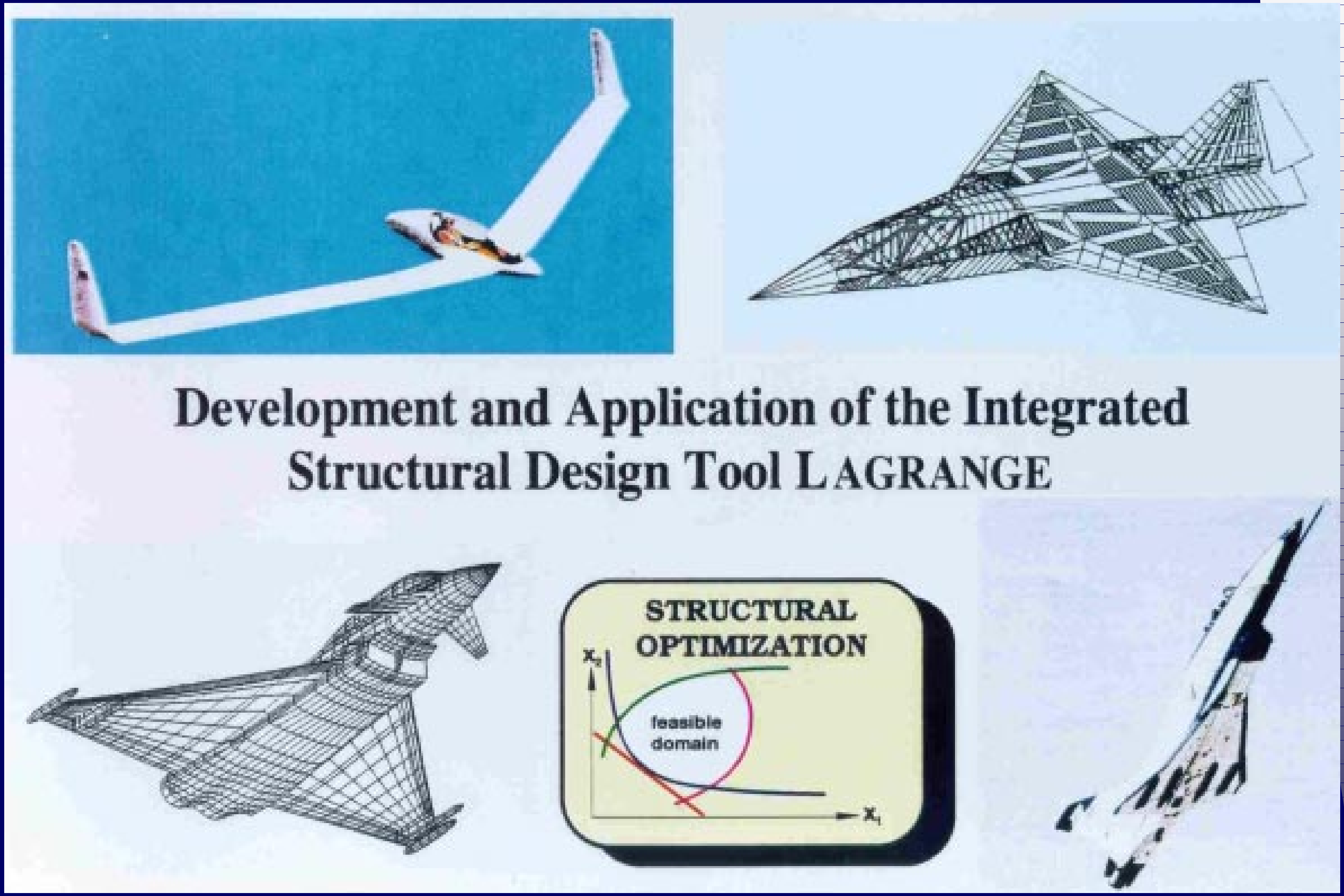
Aeroelastic Tailoring and Structural Optimization

- Developed under US Air Force Contract (by GD)
- Plate model for wing structures
- Variables: polynomial coefficients for thickness, fiber angles, lumped masses
- Objectives and constraints: weight, flutter speed, aeroelastic effectiveness, frequencies, deformations (twist, camber)
- Flexible drag polars
- Aeroelastically trimmed loads
- Features added at Dasa:
  - additional optimizer (MOM)
  - unsteady supersonic aerodynamics
  - calculation of hinge moments
  - FEM generator for results

LAGRANGE Features

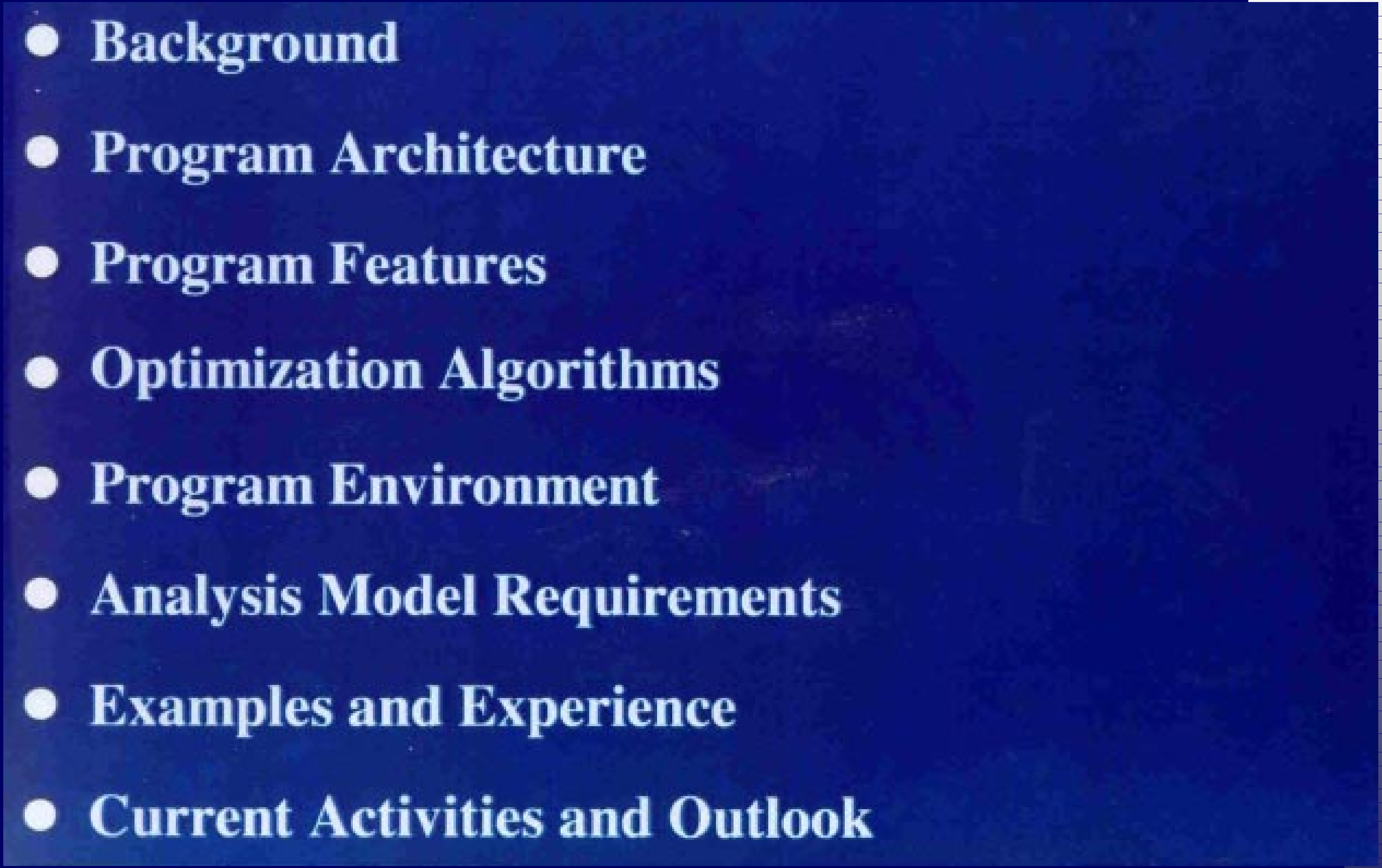
- NASTRAN input for FEM
- Various optimizers for all classes of problems
- Various optimizers for all classes of problems
- Direct link to NC tape laying
- Calculation of flutter speed for correct Mach no.
- Variables: sizing, lumped masses, geometry
  (variable fiber angles, grid point coordinates)
- Generation of aeroelastically adjusted loads
- Simulation of active structures for aeroelastic analysis
- Adaptation to CFD codes (Euler, Navier-Stokes)
- Modifications for tow steering design and manufacturing
- Model updating by test results, failure detection,
  health monitoring

LAGRANGE as an example



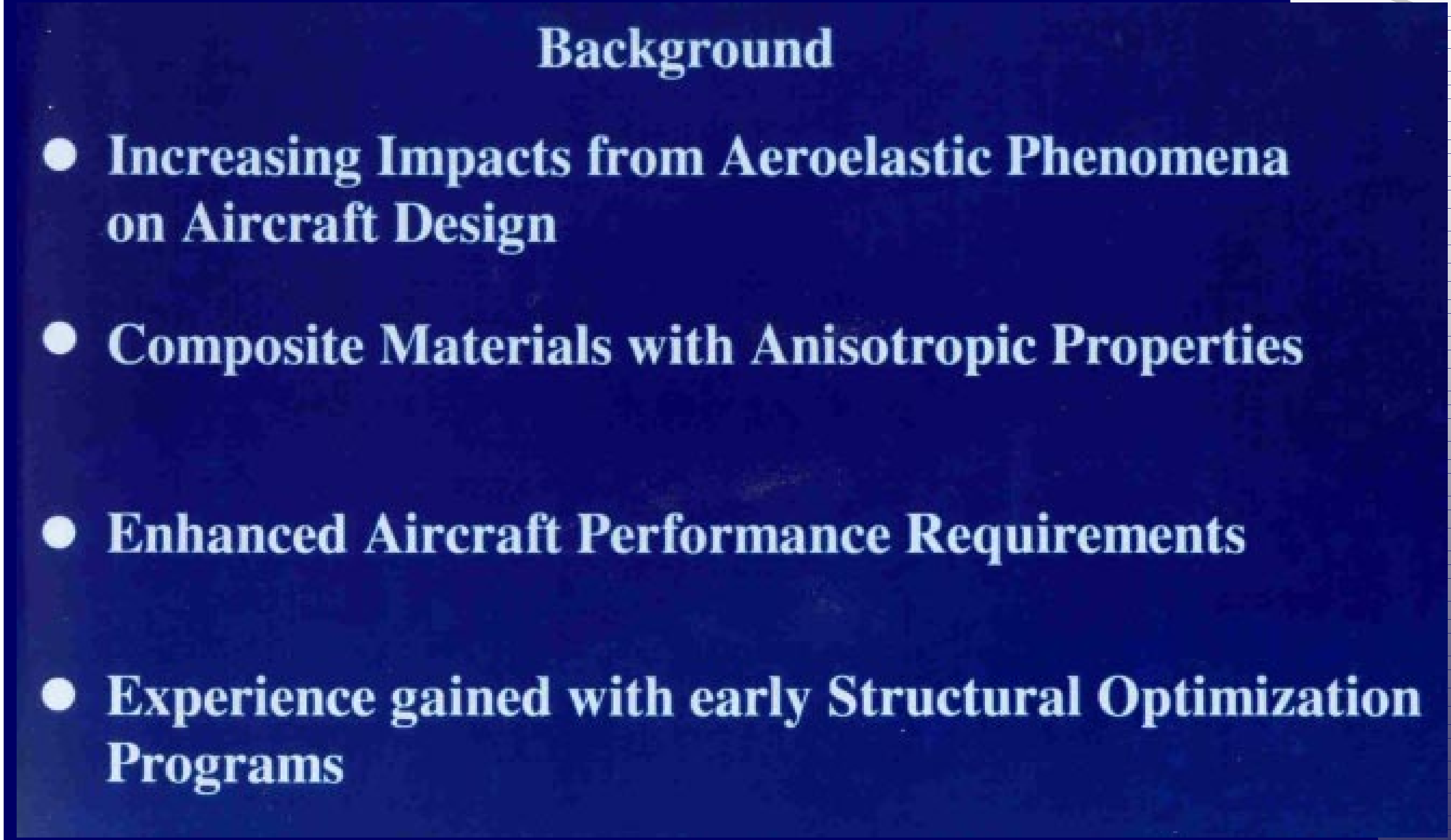
Development and Application of the Integrated Structural Design Tool LAGRANGE

LAGRANGE Overview



- Background
- Program Architecture
- Program Features
- Optimization Algorithms
- Program Environment
- Analysis Model Requirements
- Examples and Experience
- Current Activities and Outlook

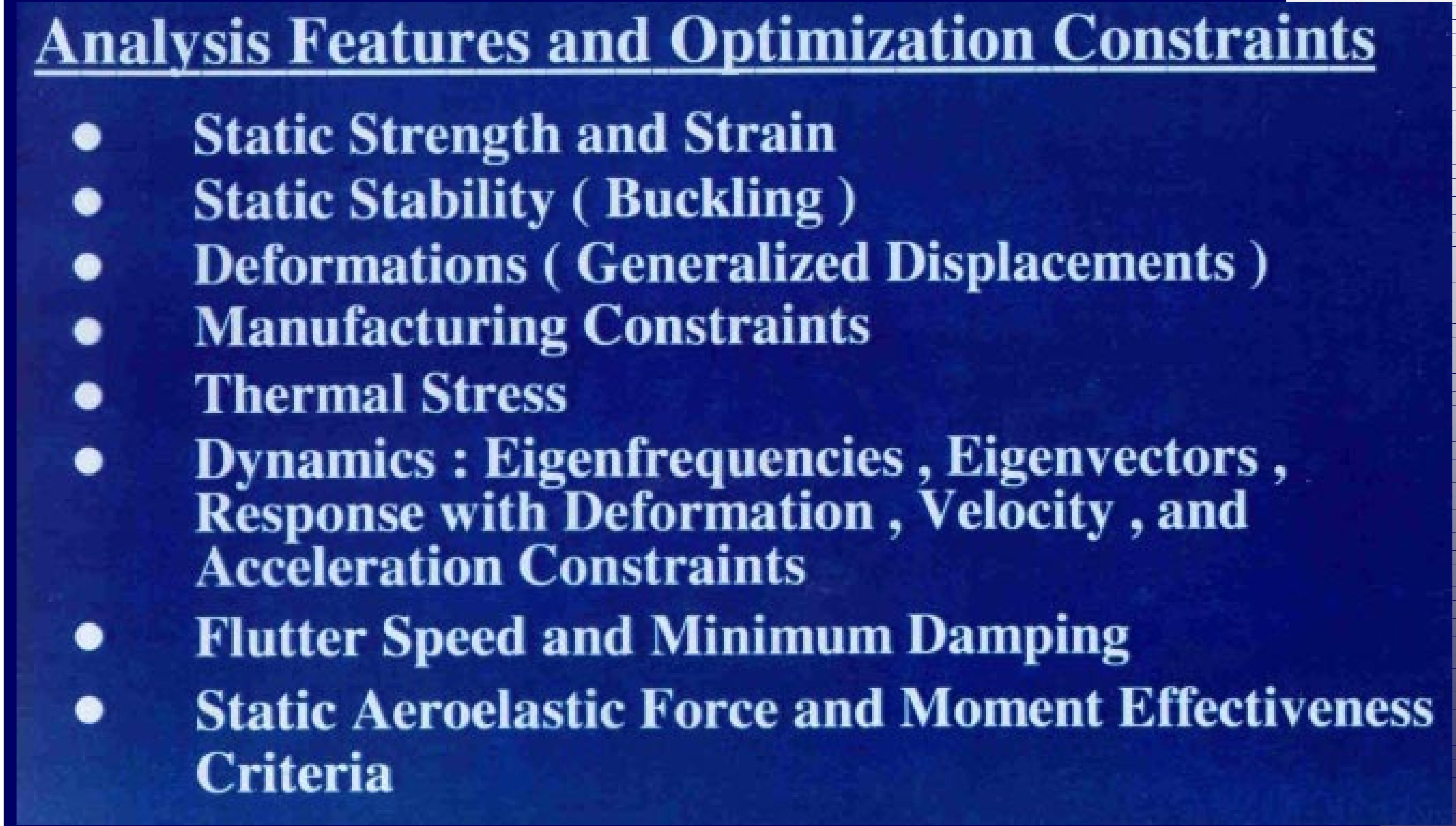
LAGRANGE-3



Background

- Increasing Impacts from Aeroelastic Phenomena on Aircraft Design
- Composite Materials with Anisotropic Properties
- Enhanced Aircraft Performance Requirements
- Experience gained with early Structural Optimization Programs

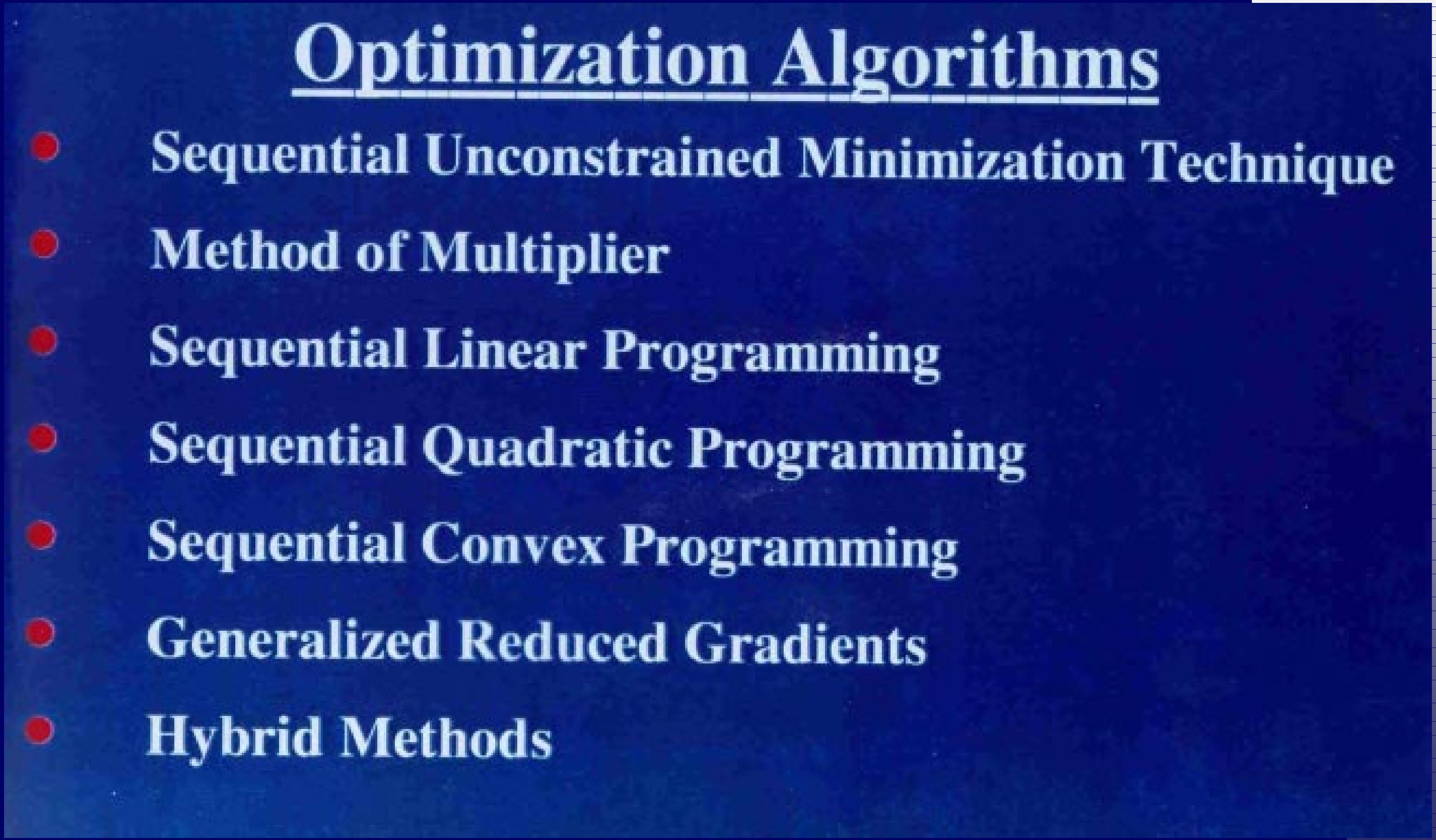
LAGRANGE-4



Analysis Features and Optimization Constraints

- Static Strength and Strain
- Static Stability (Buckling)
- Deformations (Generalized Displacements)
- Manufacturing Constraints
- Thermal Stress
- Dynamics : Eigenfrequencies , Eigenvectors , Response with Deformation , Velocity , and Acceleration Constraints
- Flutter Speed and Minimum Damping
- Static Aeroelastic Force and Moment Effectiveness Criteria

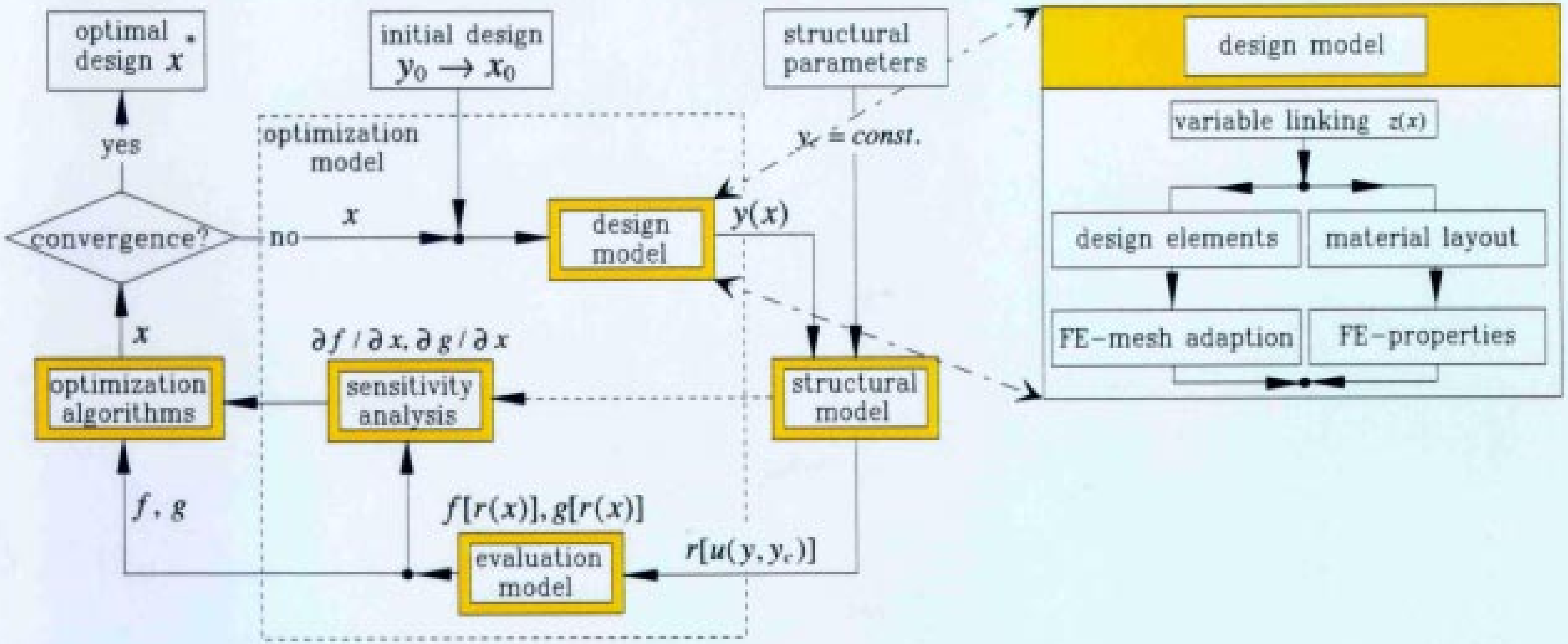
LAGRANGE-5



Optimization Algorithms

- Sequential Unconstrained Minimization Technique
- Method of Multiplier
- Sequential Linear Programming
- Sequential Quadratic Programming
- Sequential Convex Programming
- Generalized Reduced Gradients
- Hybrid Methods

LAGRANGE-6



LAGRANGE Program Architecture