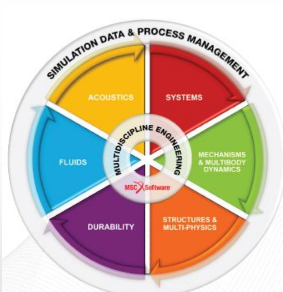
WORKSHOP*

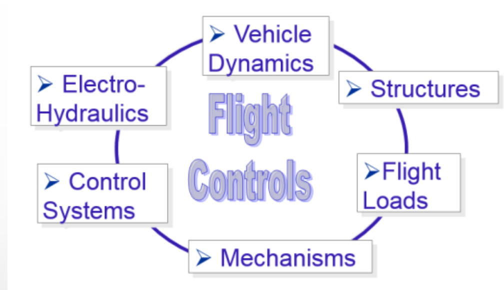
High Lift Device

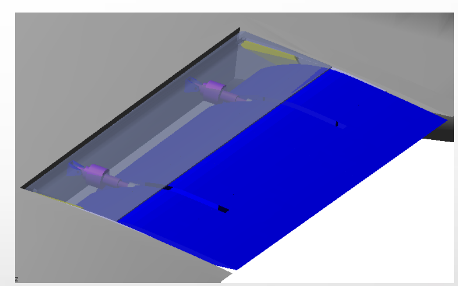
Multibody, FEM, CFD, Controls

Daniele Catelani

Senior Project Managers MSC Software

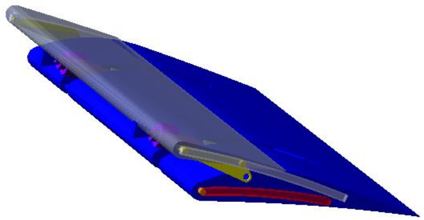






*SHORT VERSION

High-Lift Device (Flap)



- **Objective:**
  - Design and Analysis of Flap
    - CAD - Multibody: CAD Interoperability
    - Multibody:
      - Kinematic analysis: mechanism verifications
      - Dynamic analysis: actuator sizing
      - Compliances: loads evaluation, vibration
    - FEM – Multibody:
      - Flexible bodies: dynamic analysis
    - CFD – FEM – Multibody:
      - Aerodynamic forces

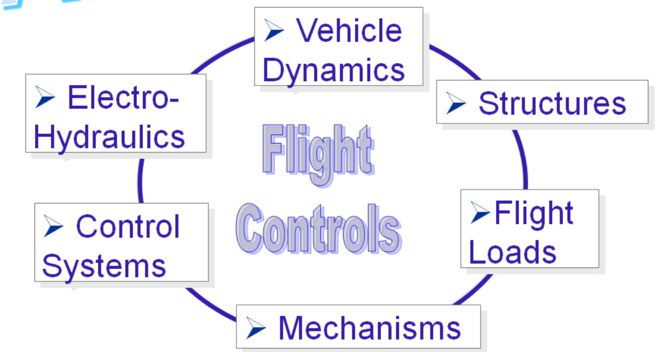
PARTIAL

    - Multibody and EASY5:
      - Mechatronics

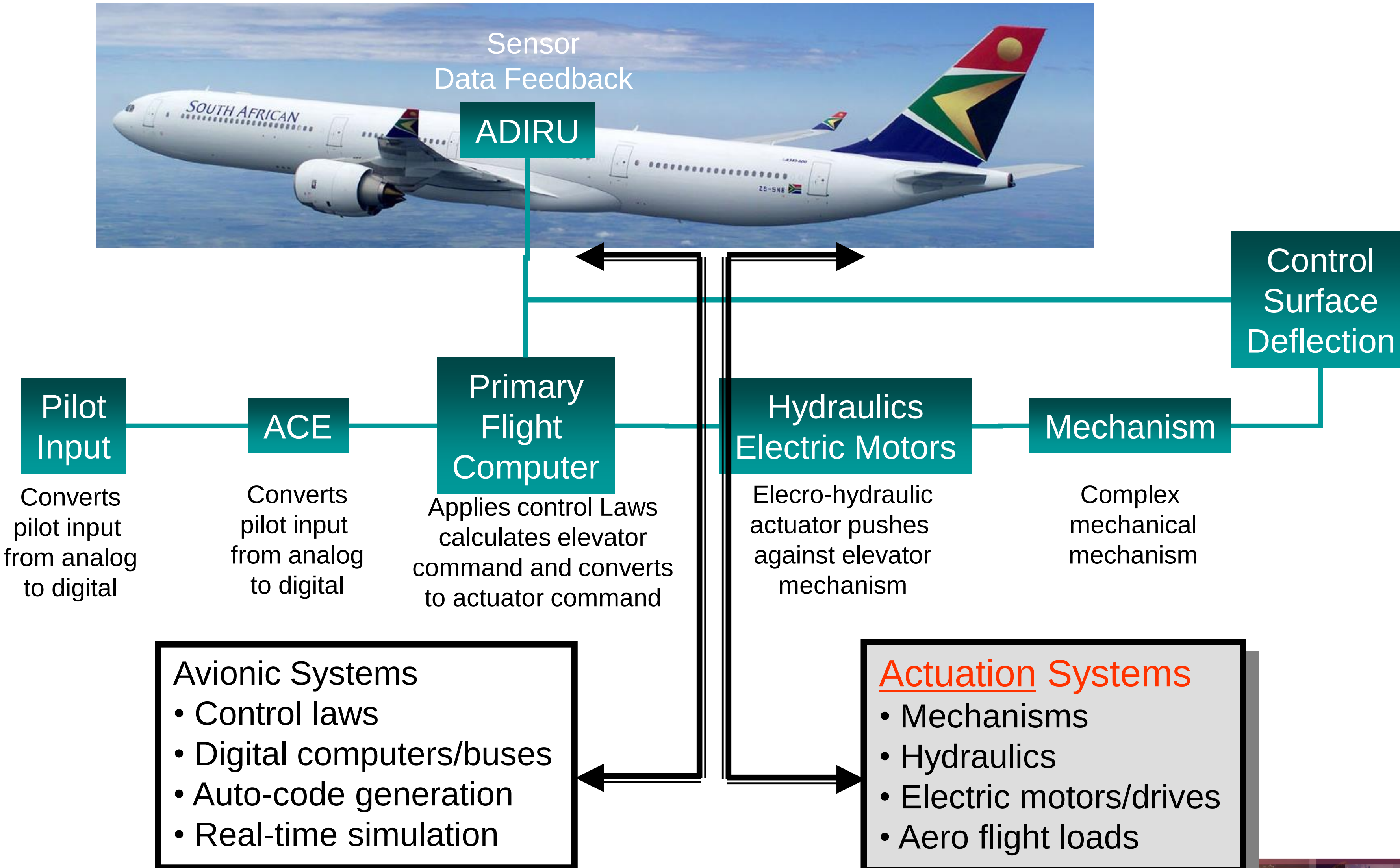
NO

    - Multibody – FEM:
      - Durability,Stress Recovery
      - Fatigue analysis

PARTIAL



Actuation Systems: FCS



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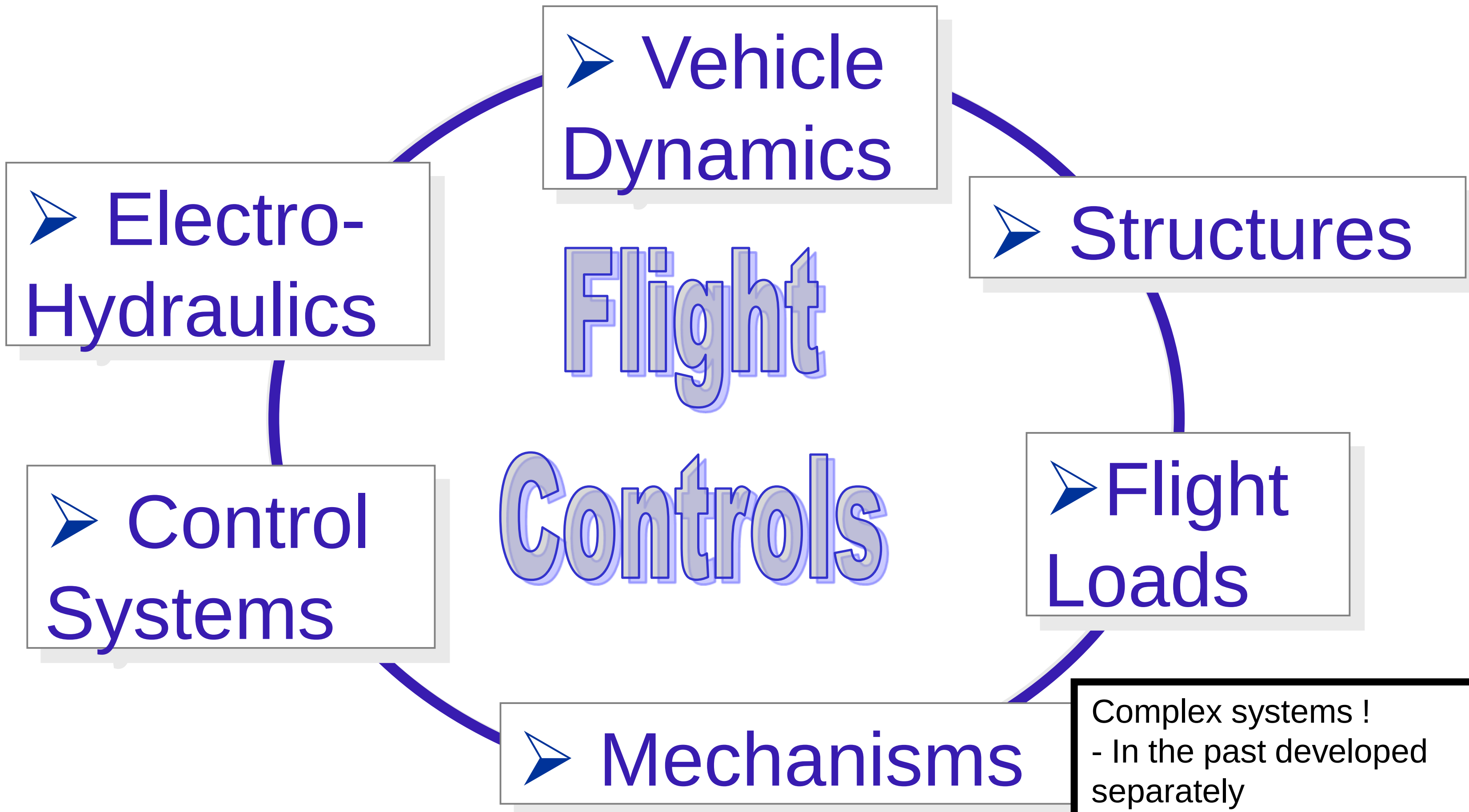
Flight Controls: MultiDisciplinary Systems

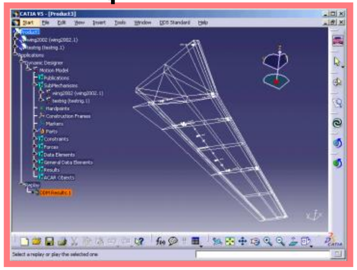


Complex systems !
- In the past developed separately
- Integrated and physically tested at the end of development phase
- Very costly to correct problem

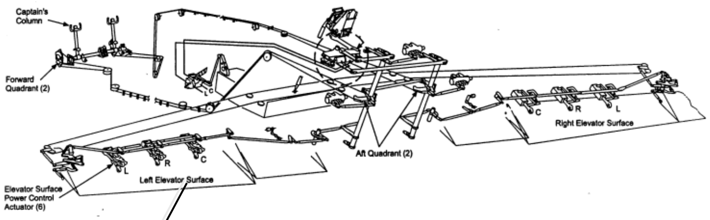
Industry Process:"Iron Bird" Physical Testing

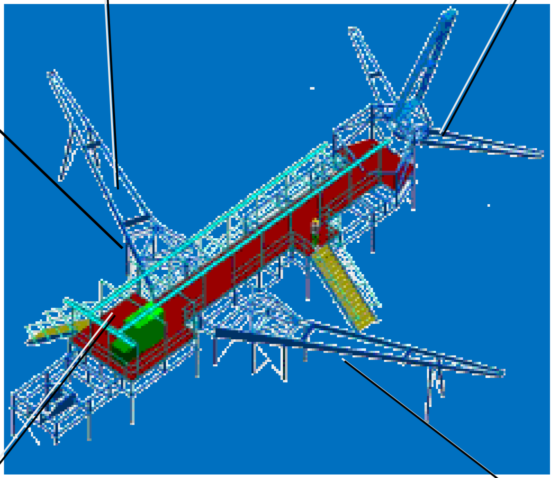
Actuation

Components



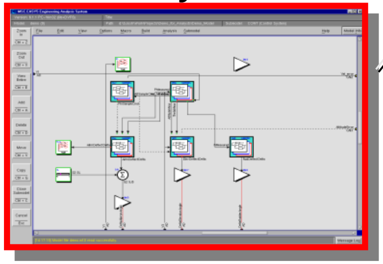
Kinematics & Dynamics



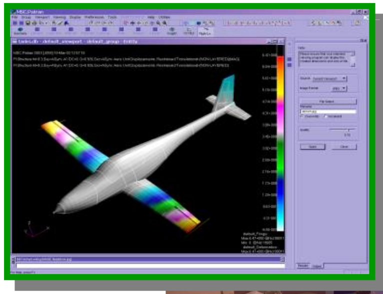


Iron Bird (skeleton aircraft):
Systems Integration
& Functional Test
Real-time

Control System

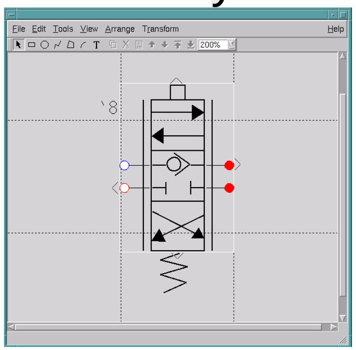


External Loads



MSC Flight Control Tools

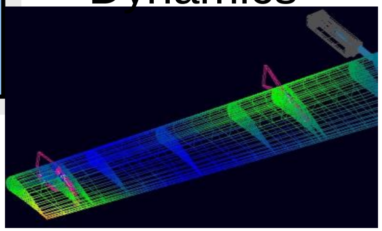
Hydraulics & Control Systems



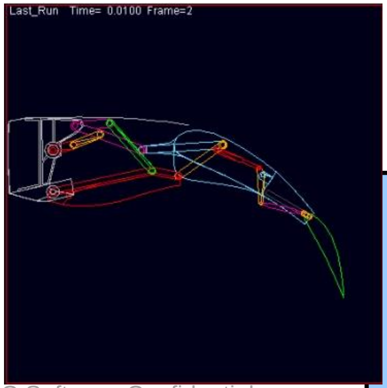
EASY5

Nastran
Patran

Structural Dynamics

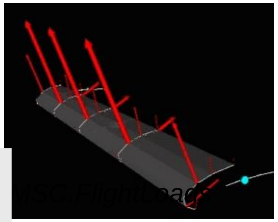


Mechanism design



ADAMS

Flight Loads



FlightLoads

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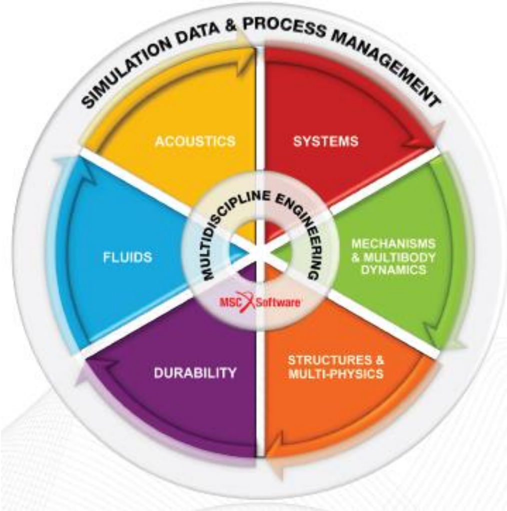
MSC Flight Control Tools

Integrated VPD Environment



- **Reduce risk & cost**
  - uncover problems earlier in flight controls design process before Iron Bird testing
- **Improve quality**
  - Better validated flight control systems before flight tests
- **Integrate multi-disciplinary tools improve product development**

MSC Flight Control Tools

- **Complete environment for design and analysis of flight controls**
  - Effect of wing warping on mechanism due to structural deflection
  - Distributed aero loads vs. point load
  - Environmental disturbances – thermal, aerodynamics
  - Test complete aircraft and flight controls through flight maneuvers
  - Nonlinear controls that effect flying qualities and overall safety
  - Evaluate hydraulic actuation and effect of back force
  - Effect of preload condition, excessive friction or system stiffness in mechanism design
  - Perform tradeoff studies of surface flexibility, track shape, drive system authority, and configurations
  - Perform systems integration before Iron Bird assembly

- **Reduce risk**
- **Reduce (not eliminate) physical prototyping**
- **Reducing risk and testing = reduces cost**

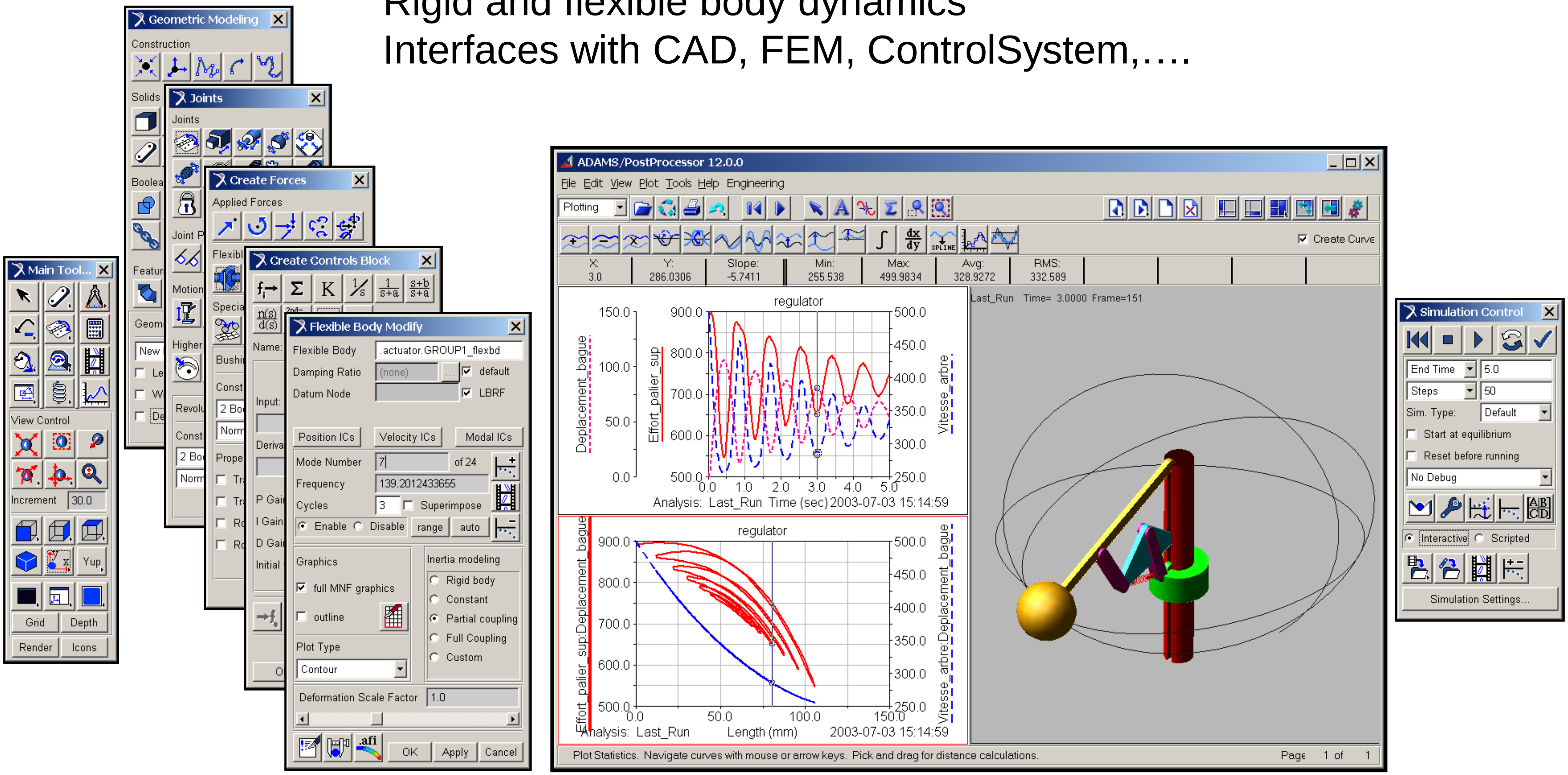
MSC.ADAMS

Mechanical motion simulation tool

- Multi-body dynamics and kinematics

Rigid and flexible body dynamics

Interfaces with CAD, FEM, ControlSystem,….



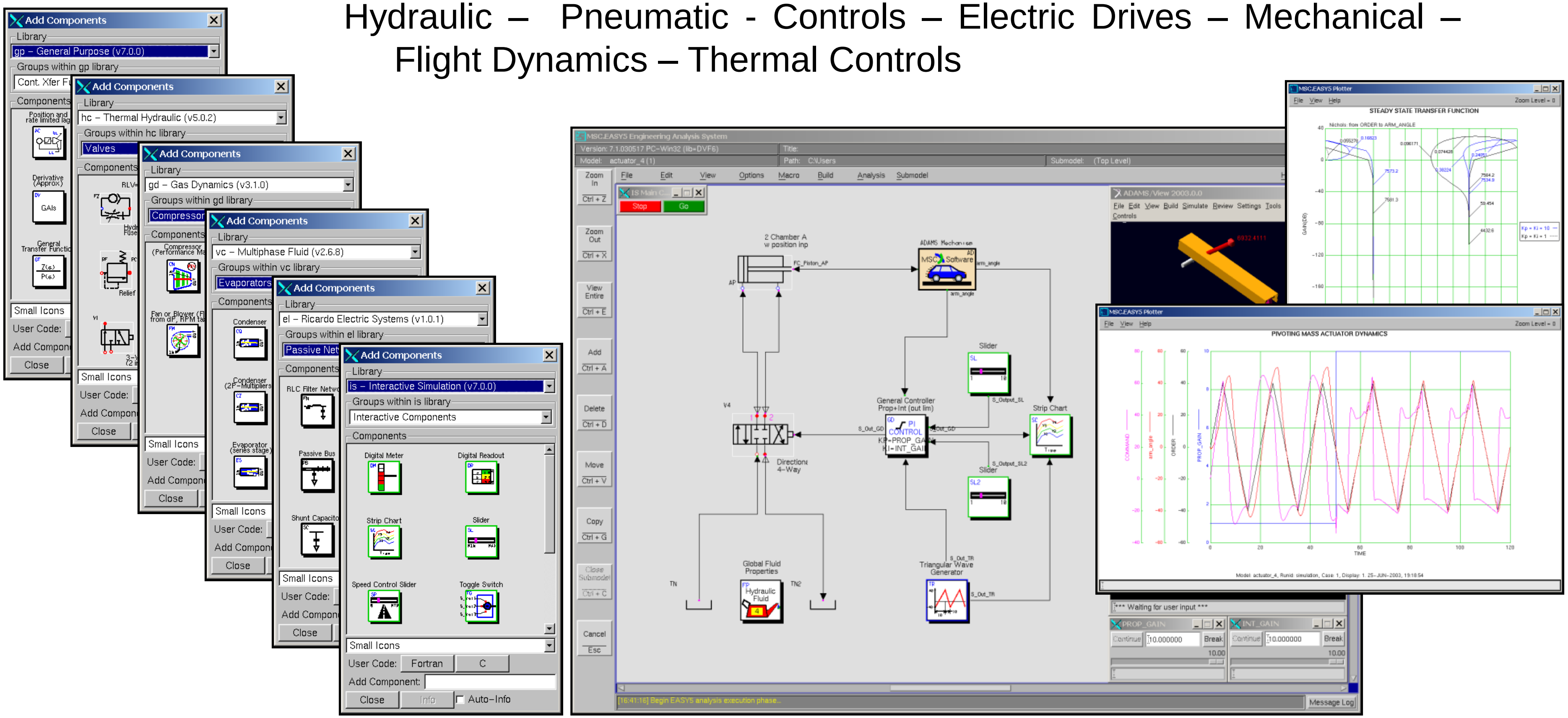
MSC.EASY5

Systems-level modeling tool based on schematic block-diagram view of engineering systems

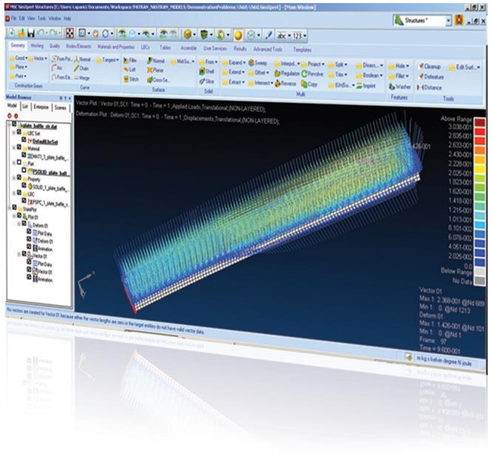
- Modeling – Design – Linear & Nonlinear Analysis

Multi-disciplinary

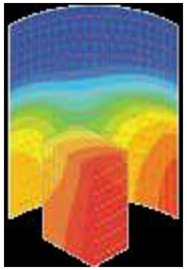
Hydraulic – Pneumatic - Controls – Electric Drives – Mechanical – Flight Dynamics – Thermal Controls

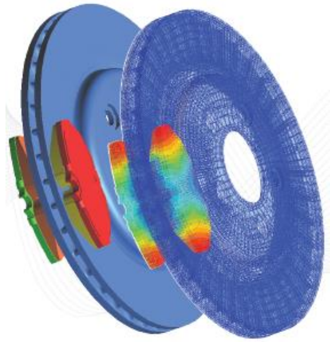


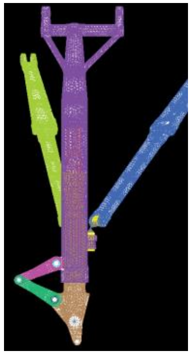
MSC.Nastran (Patran as pre-post)



- World's most widely used Finite Element Analysis solver
- Most trusted multidiscipline solver in the world.
- To simulate from a single component to complex assemblies under diverse conditions.
- Offers complete set of linear static and dynamic analysis capabilities
- Support for superelements
- Offers set of implicit and explicit nonlinear analysis capabilities
- Enables thermal and interior/exterior acoustics
- Enables coupling between various disciplines such as thermal, structural, and fluid interaction







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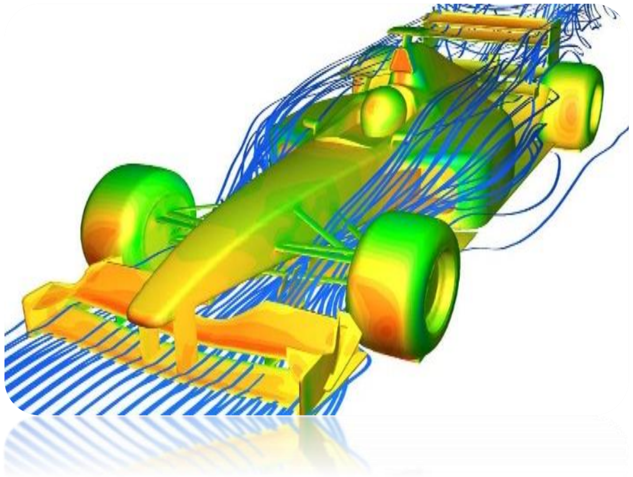
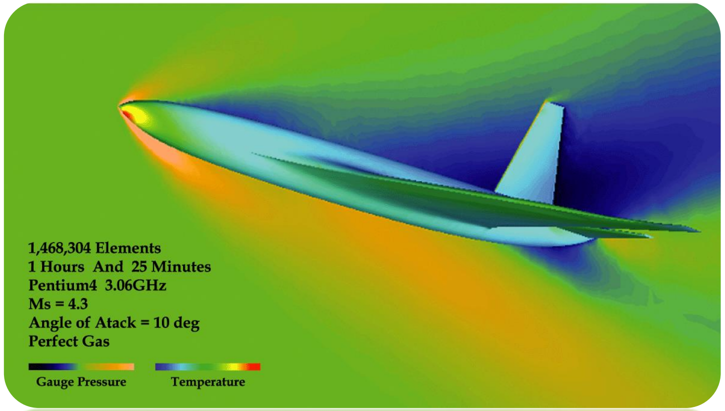
Cradle

- Computational Thermo-Fluid Dynamics is a simulation tool used to analyze complex thermal and fluid phenomena
- Navier-Stokes equations for fluid-dynamics are used in CFD and further specific models for complex phenomena are employed as well
- CFD allows to predict products' performance before performing experimental tests, with a great saving in terms of time and money
- It can be implemented in a wide range of industrial sectors, since CFD is able to study any component/system involving fluid-dynamics and heat exchange





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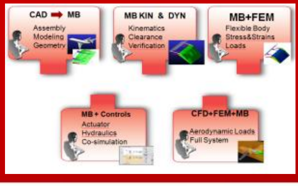
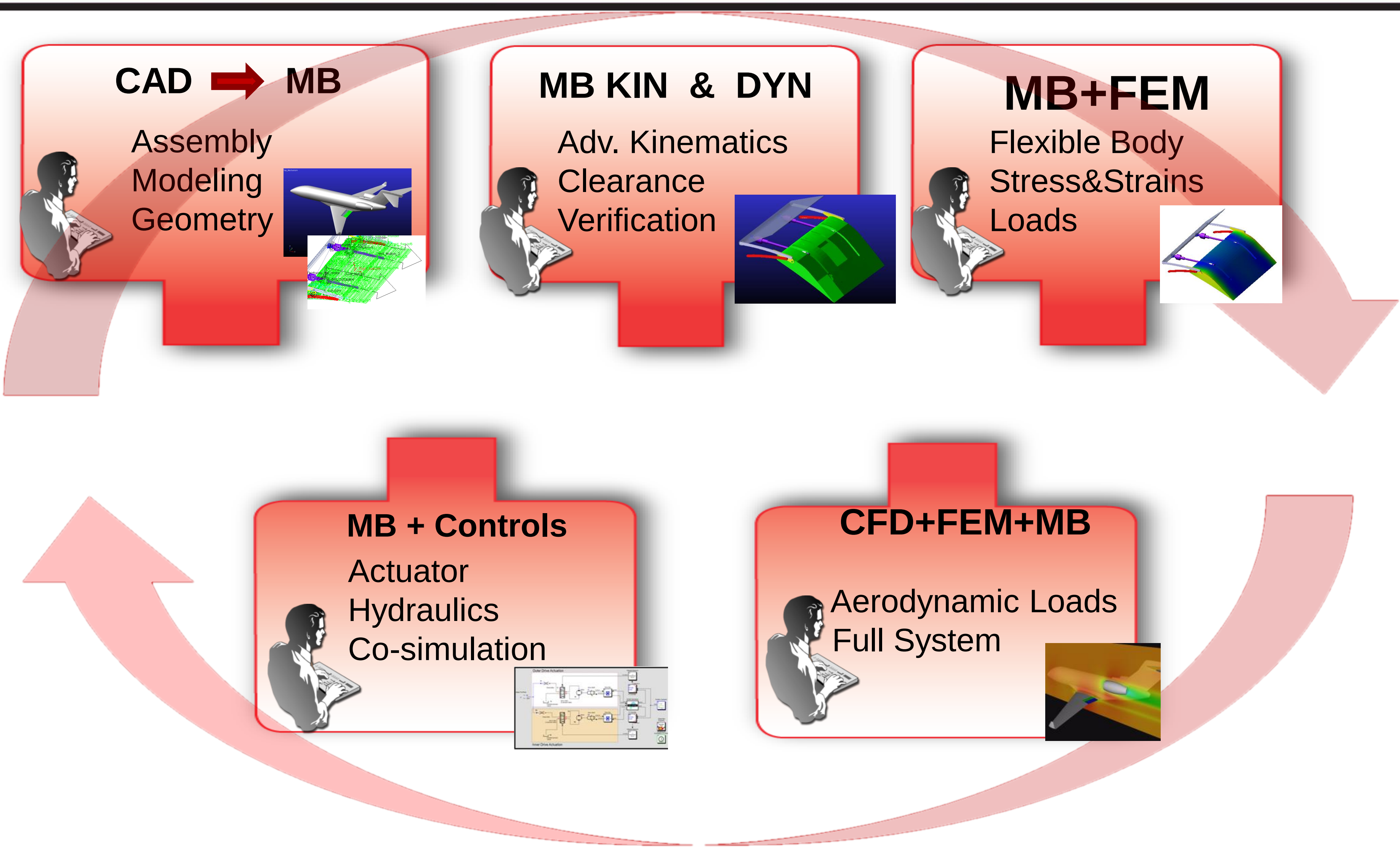
Multidiscipline analysis





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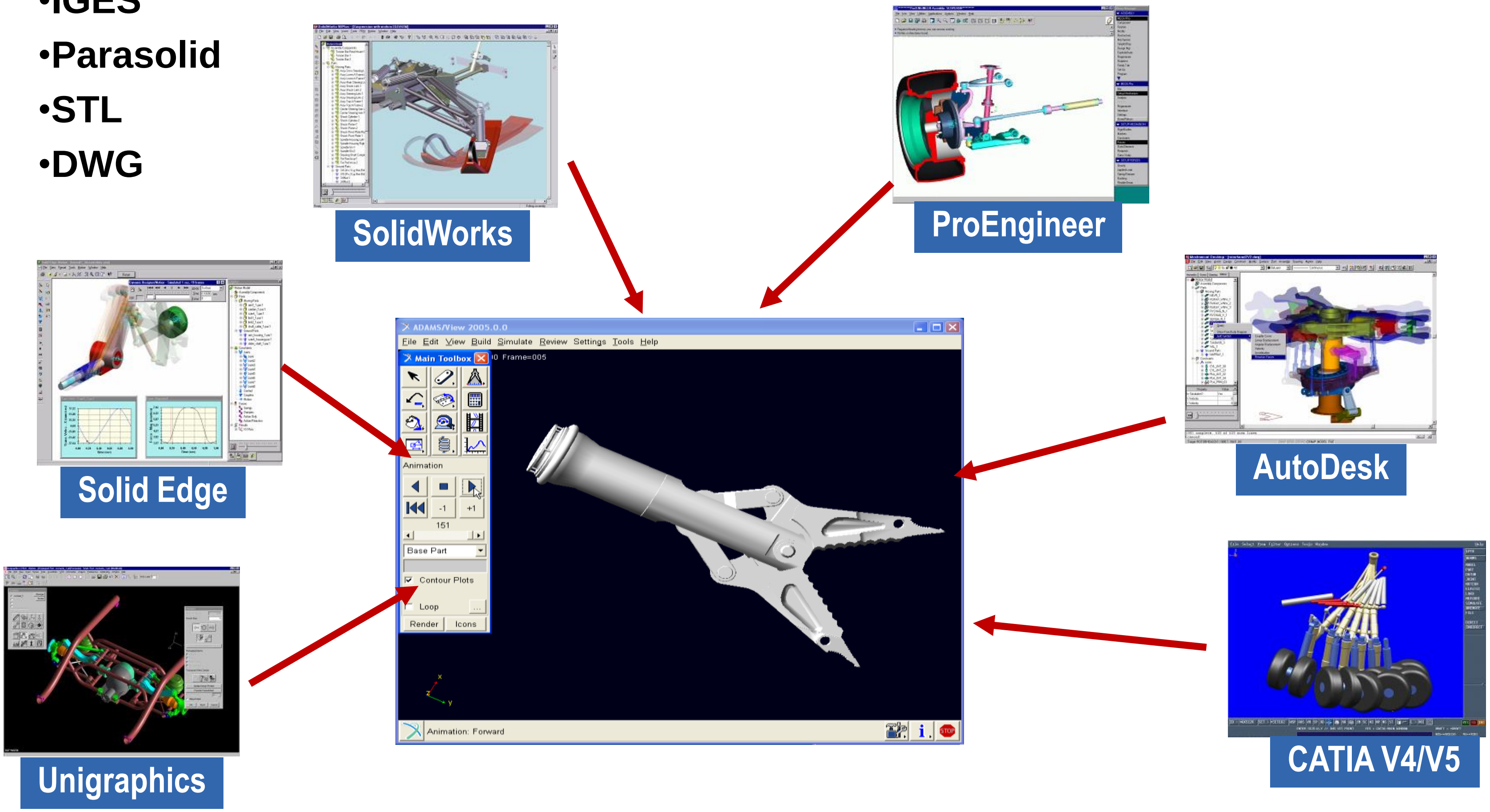
CAD – Multibody: Geometry Import/Export

Import and Export of CAD geometry:

- STEP
- IGES
- Parasolid
- STL
- DWG



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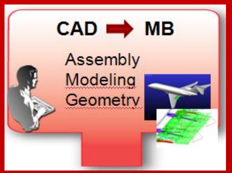
CAD – Multibody: CAD Interoperability

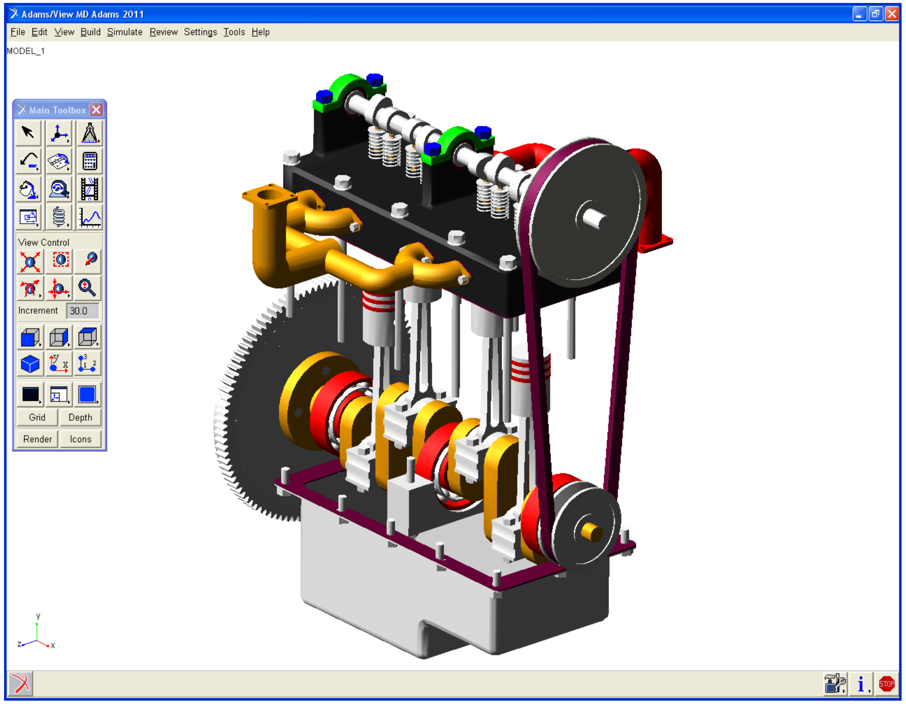


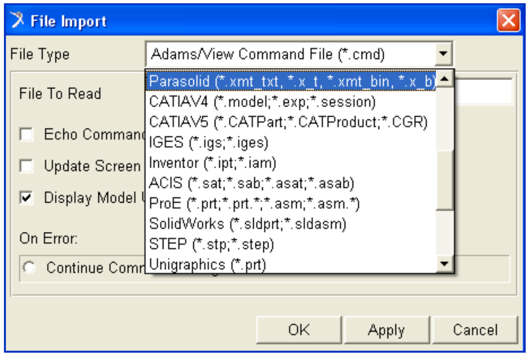
DIRECT Import and Export from CAD geometry:

- CATIA V4 and V5
- Pro/E
- SolidWorks
- UG NX
- Inventor
- ACIS, VDA, ecc.

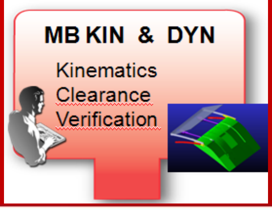
<u>Advs:</u>

- No need to use neutral format
- Direct import of full assemblies, creating rigid bodies, assigning inertia
- More accurate geometry if needed

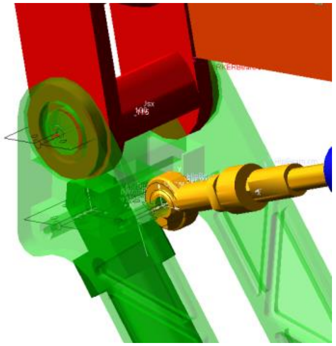




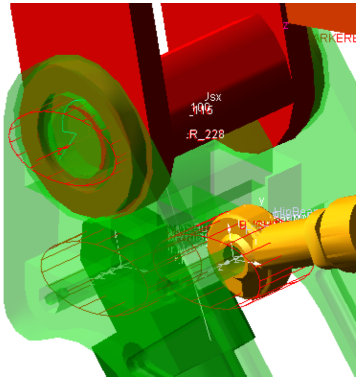
Kinematic & Dynamic Analysis



- **<u>Direct Kinematic:</u>**
  - ○ **Applied Motion evaluatin**
  - ○ **Motor Torque and Actuator force evalutation, external forces, weight, inertia, friction**
  - ○ **Kineto-static performance evaluation**
  - ○ **Clearance determination**
  - ○ **Preliminary Failure investigation**



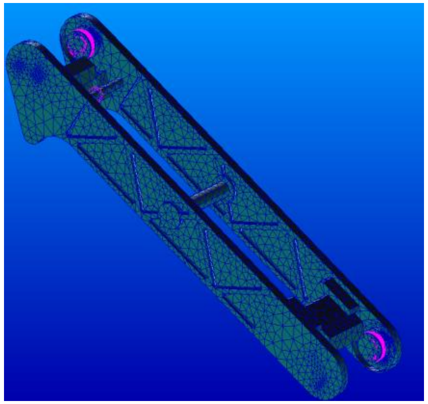
- **<u>Dynamic:</u>**
  - ○ **Actuator forces**
  - ○ **Structural loads evaluation**
  - ○ **Friction, compliances, assembly errors verification**
  - ○ **Structural deformation**
  - ○ **Clearance determination**
  - ○ **Failure investigation**
  - ○ **Verification**



Multibody & Finite Element Analysis

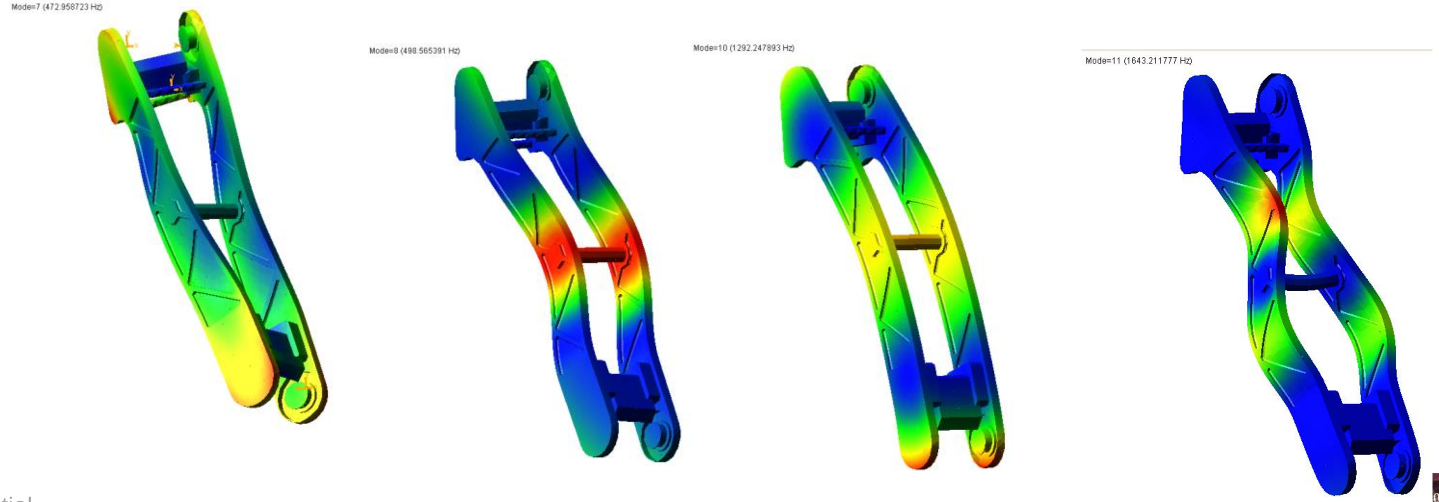
MB+FEM
Flexible Body
Stress&Strains
Loads

- **Dynamic Analysis with Flexible Bodies:**
  - **Effect of fully flexible model**
  - **Structural loads**
  - **Errors**
  - **Vibration**
  - **Deformation**
- **Stress & Strain evaluation**
- **Durability and Fatigue Analysis**



FEM model

Modal description



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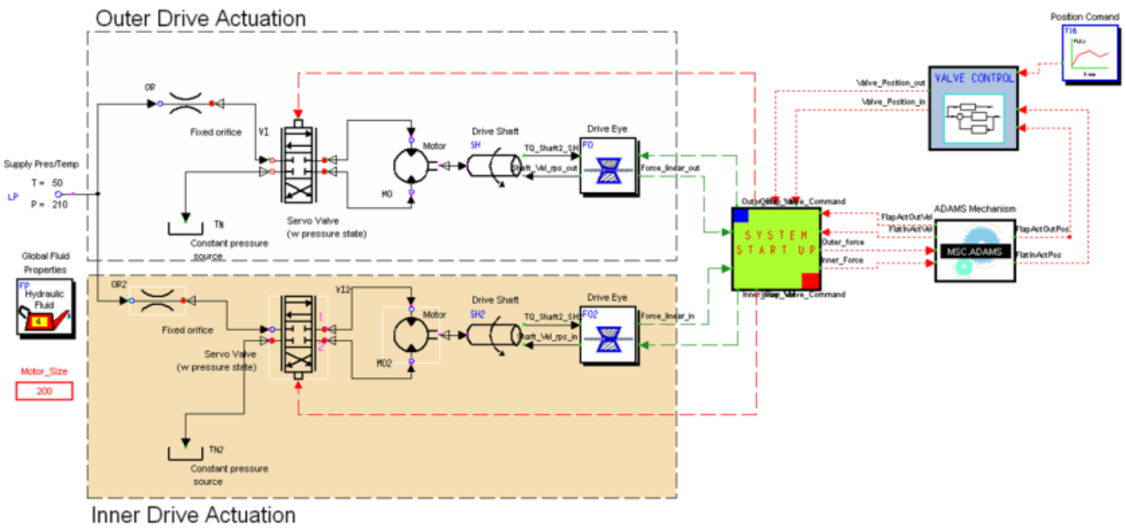
Multibody & Control Analysis

•**Mechatronic analysis**
  - ○ **System control**
  - ○ **Hydraulic/Multibody system interaction**
  - ○ **Realistic Actuator modelization**
  - ○ **Cosimulation**



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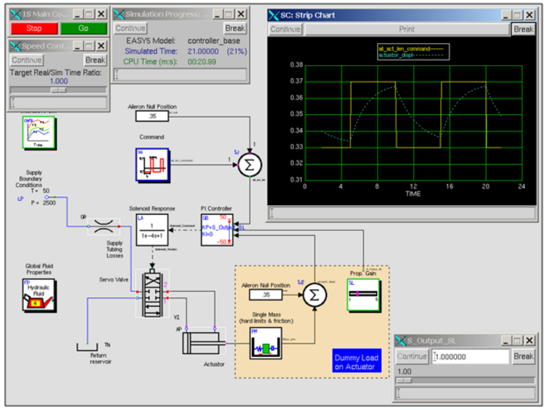
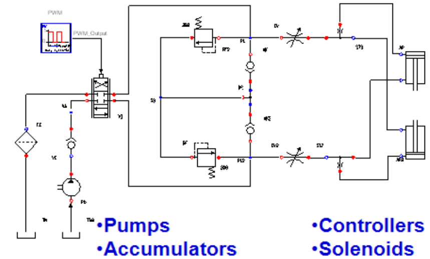
Multibody & Control Analysis



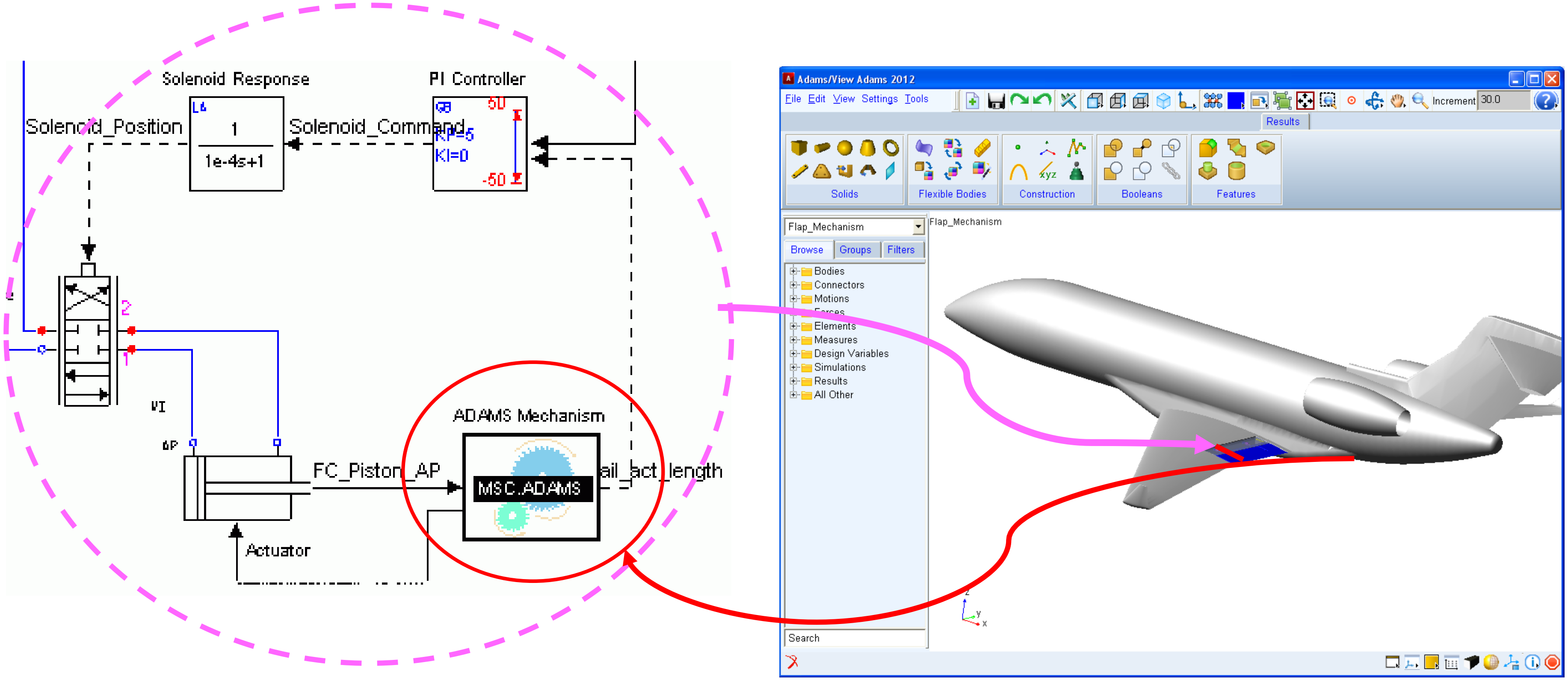
- **EASY5: rich component libraries**
  - **hydraulics**
  - **pneumatic**
  - **electric**



•Valves	•Pumps	•Controllers	•Motors
•Pipes	•Accumulators	•Solenoids	•Reservoirs
•Hoses	•Actuators	•Springs	•Inertias
•Filters	•Fittings	•Dampers	•Shafts
•Heat exchangers	•Orifices	•Sensors	•Volumes
•Moving masses	•Force calculators	•Flow resistances	•Leaks

Flight Controls ADAMS/EASY5 Integration

EASY5 hydraulic control system model embedded in ADAMS flight control mechanism model



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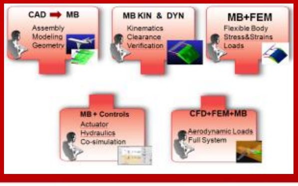
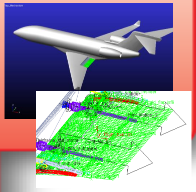
Multidiscipline analysis



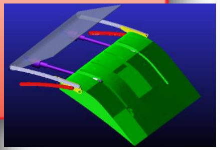
CAD ➡ MB

Assembly
Modeling
Geometry



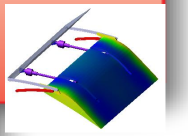
MB KIN & DYN

Adv. Kinematics
Clearance
Verification



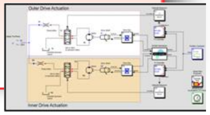
MB+FEM

Flexible Body
Stress&Strains
Loads



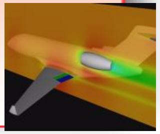
MB + Controls

Actuator
Hydraulics
Co-simulation



CFD+FEM+MB

Aerodynamic Loads
Full System



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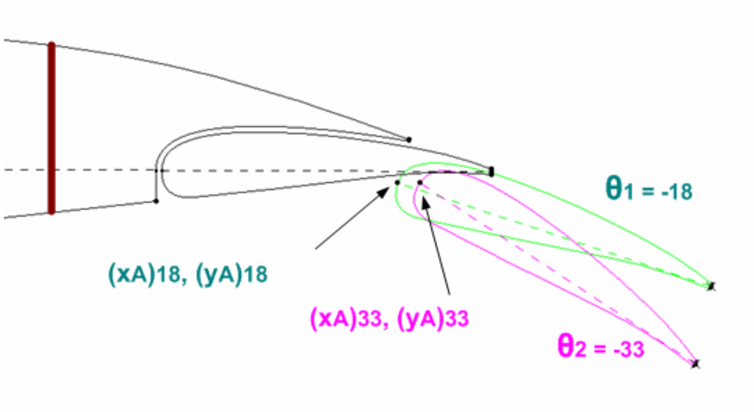
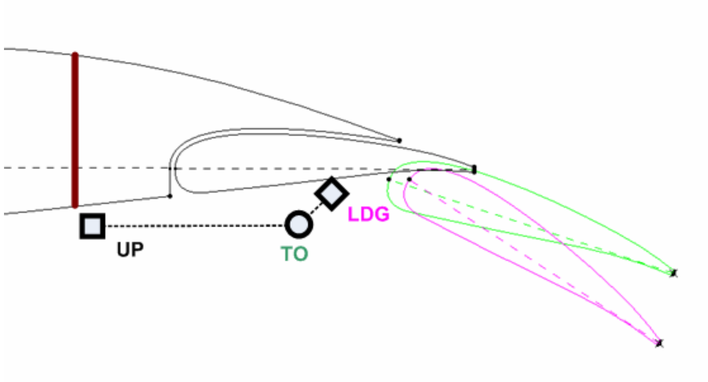
Flap model: Requirements - 0.1





For the kinematic design of actuation, the starting points are the aerodynamic requirements:

geometrical requirements

I.e: defining coordinates of point A (LE Flap) for

- TO θ = -18º
- LDG θ = -33º

means geometric constraints for coordinates XA , YA

$$(x_A)_{-18}, (y_A)_{-18}$$
$$(x_A)_{-33}, (y_A)_{-33}$$

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Flap model: Objectives - 0.2

Objectives for every configuration

A. Meet Aerodynamic Requirements
   - Coordinates Flap point for UP, TO and LDG (based of motion law)

B. Avoid interferences between Flap and TE of the wing
   - It requires a minimum gap

C. Operate in the allowed range considering links and bearings
   - Internally of Spar profile
   - Considering the Fairing profile
   - Maintain Flap integrity (position of bearings and constraints out of flap profile)

- Identify all valid configurations to allow different solutions
- Show and justify all not valid configurations

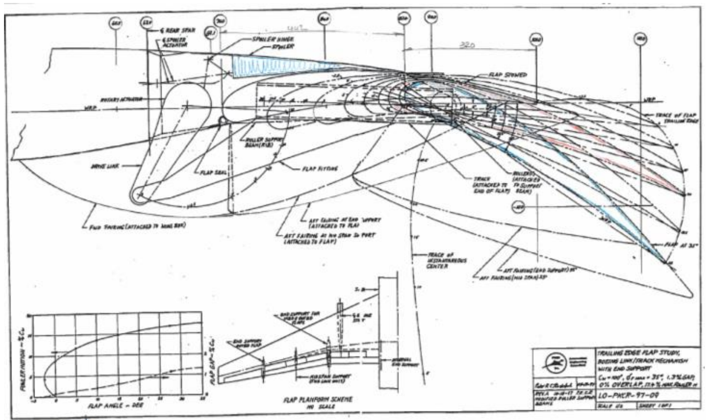

Figure 13 Boeing Type Link/Track Mechanism (End Supported)

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Flap model: Configurations - 0.3

Option 1 with variants
Rear Link + Straight Track

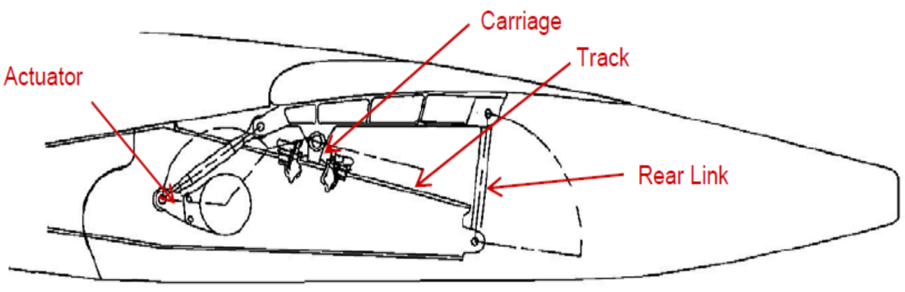
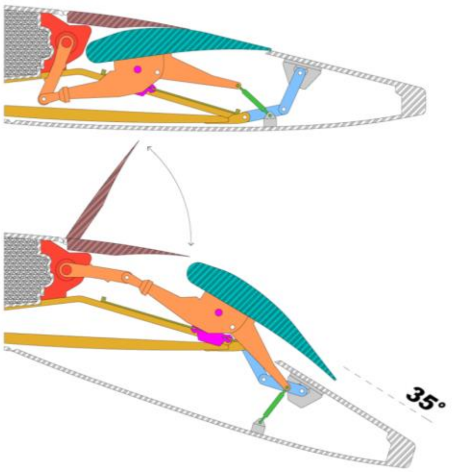
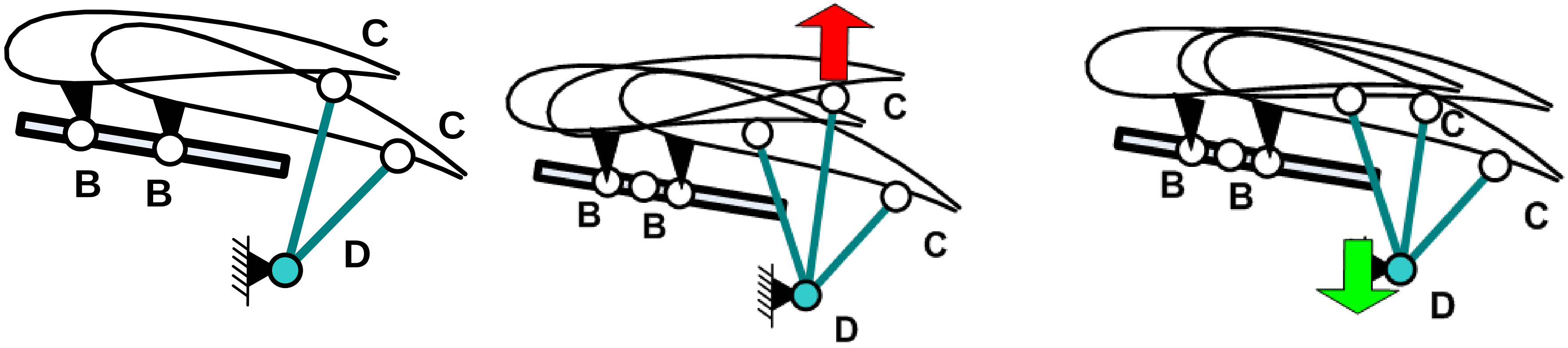


Figure 2.20 A340 flap track, according to [13]

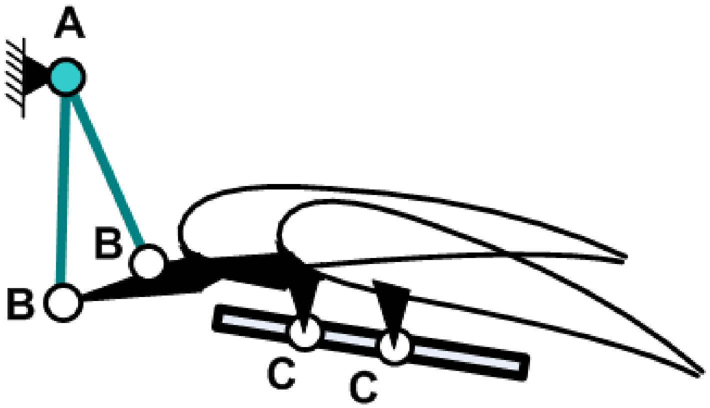


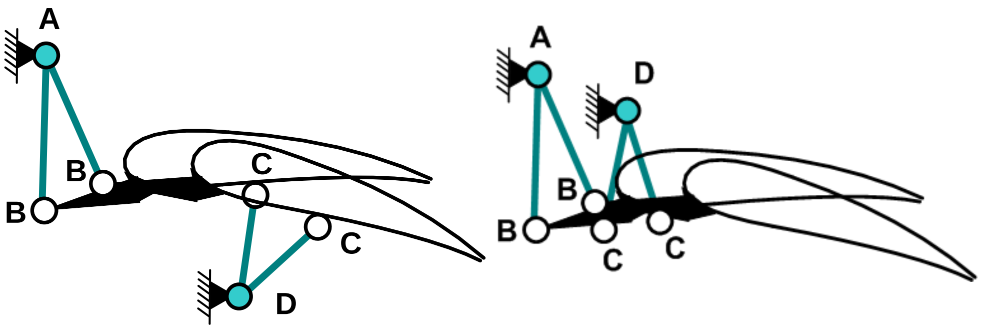


Flap model: Configurations - 0.4

Option 2
Fore Link + Straight Track

Option 3 and 3bis
Fore Link + Rear Link/Fore Link





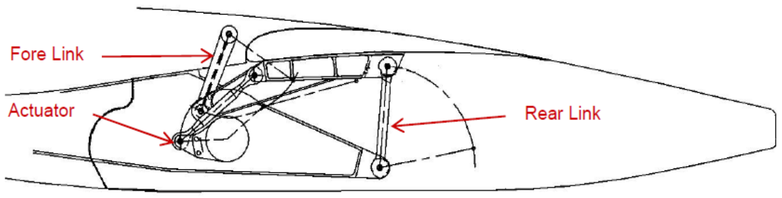
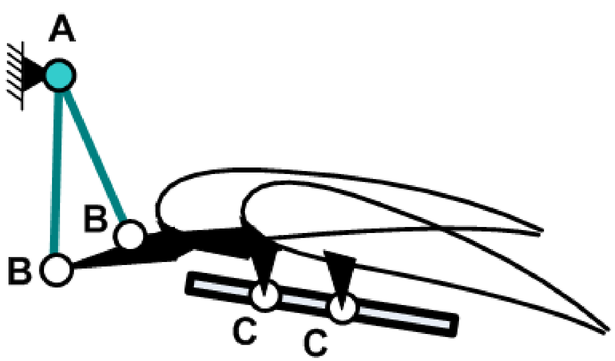


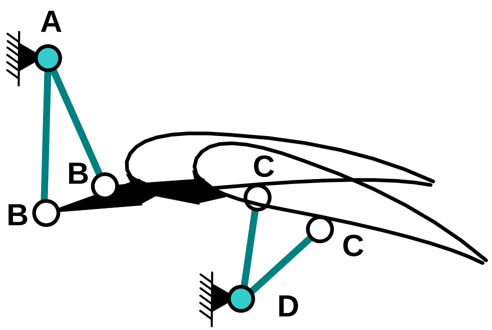
Figure 2.21 A380 flap track (not drawn to scale with Figure 2.20!), according to [13]

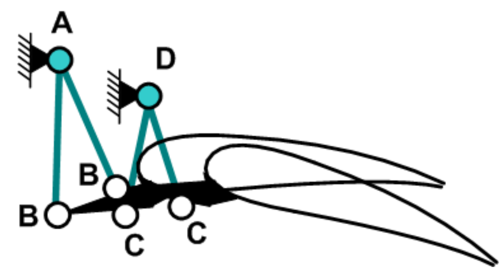
Flap model: Configurations - 0.5

Option 2
Fore Link + Straight Track



Option 3 and 3bis
Fore Link + Rear Link/Fore Link





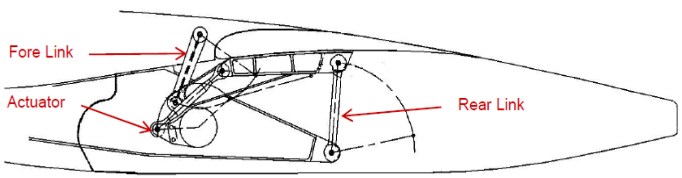
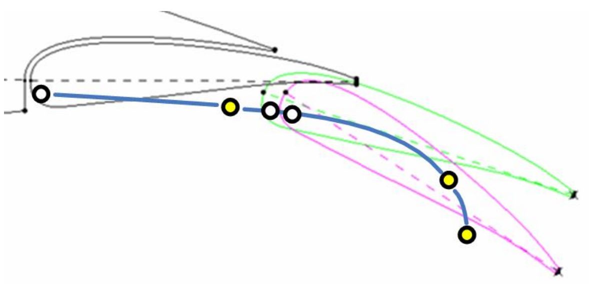


Figure 2.21 A380 flap track (not drawn to scale with Figure 2.20!), according to [13]

Opzion 4
Curved track



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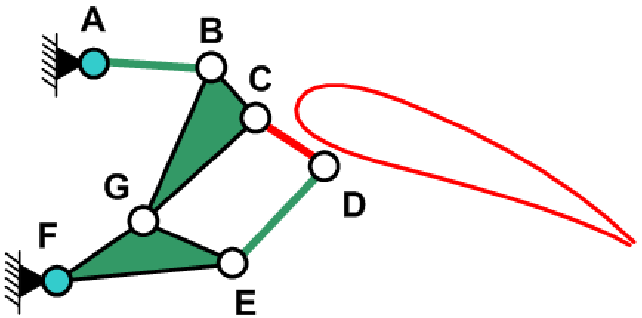
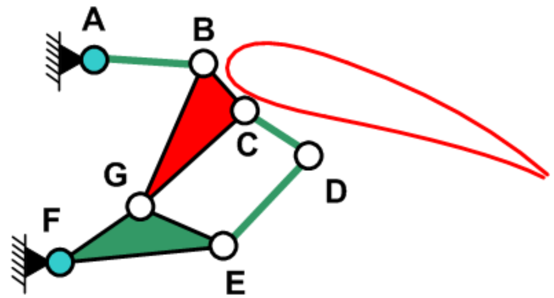
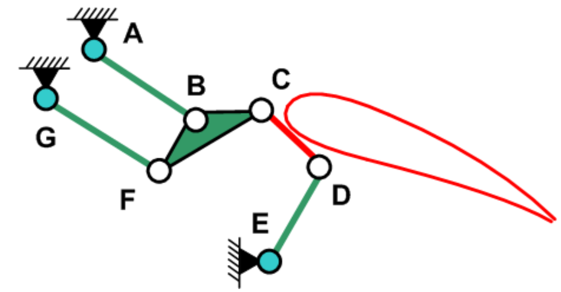
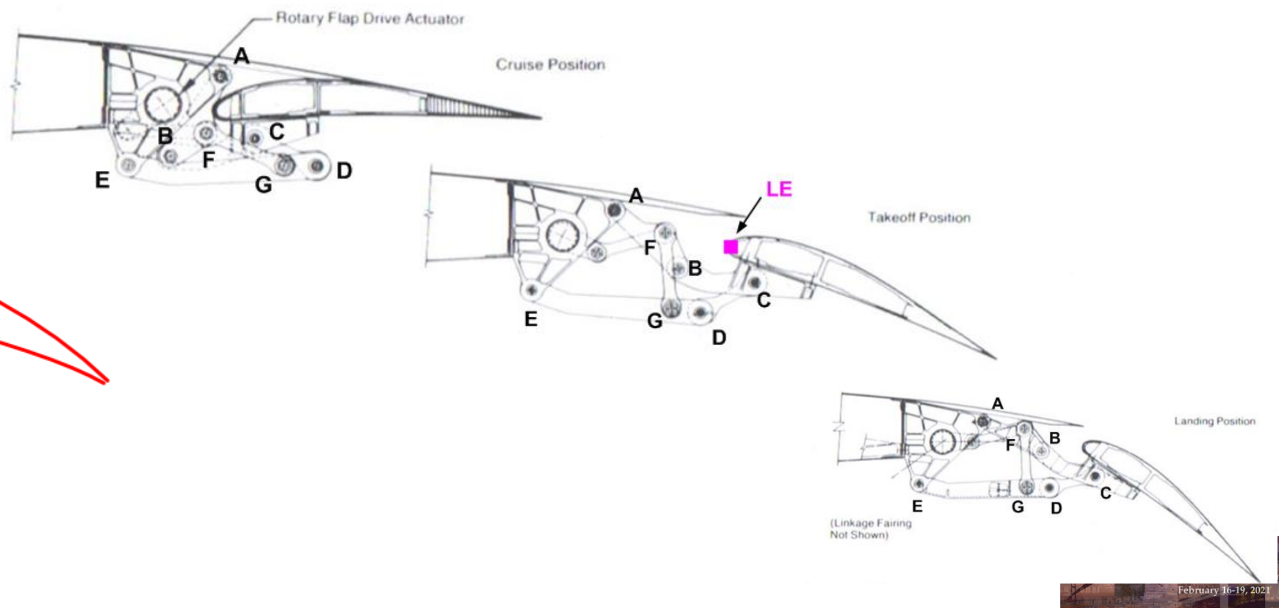
Flap model: Configurations - 0.6

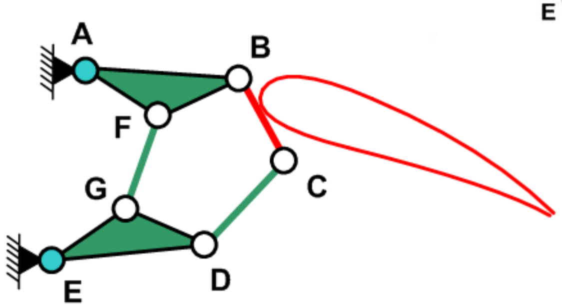
Option 5
6-bar Linkage



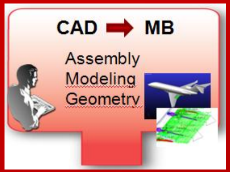




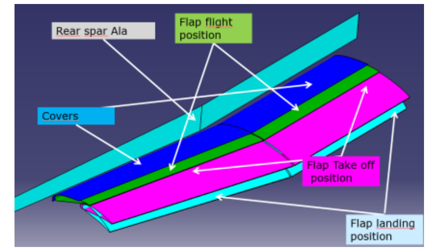




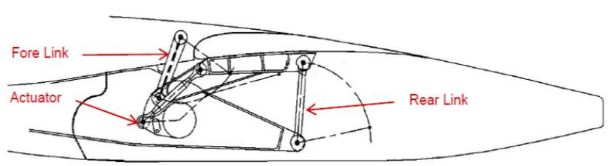
Flap model: Kinematic mechanism - 0.7

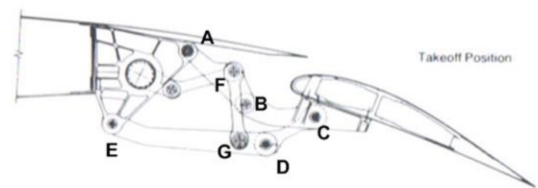


- **Preliminary Design: choice of the kinematic mechanism:**
  - Import from CAD of the simplified flap geometry for:
    - Get geometrical information for bearing and link position and interferences
    - Get/define flap trajectory for extraction and retraction at UP, TO, LDG



  - Build simple Adams model of the flap, but fully parameterized on terms of points (HP) and coordinates for joints and links for every configuration to investigate

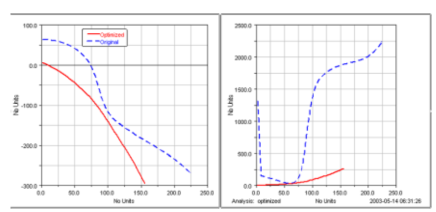


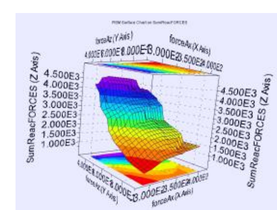


  - Define Measures and objectives (allowable full movement, no locked-up positions, no interferences, no violation of limits and trajectory)

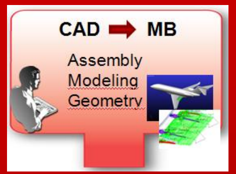
  - DOE and Optimization Run using Adams and Adams/Insight to define the best kinematic mechanism

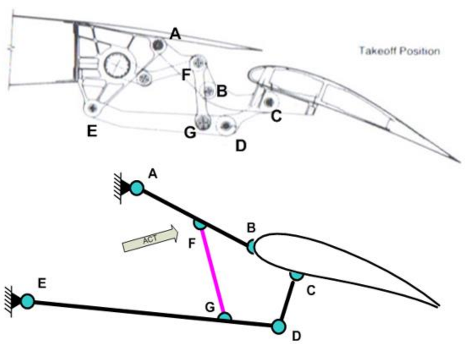
ID	Marked	p4Xi	p2Zi	p4Zi	p3Zi	forceAx	forceAz	p3xi	p2xi	SumReacF...	p6To	p3To
53	✓	-1.561E2	7.833E1	6.889E1	8.611E1	-3.067E2	9.500E1	-2.000E2	-3.722E2	6.366E2	-1.862E1	-1.138E1
130	✓	-1.617E2	7.167E1	6.889E1	8.611E1	-2.933E2	8.833E1	-2.222E2	-3.944E2	6.726E2	-1.954E1	-1.142E1
131	✓	-1.561E2	7.500E1	6.889E1	9.500E1	-2.800E2	8.833E1	-2.111E2	-4.278E2	3.674E2	-1.267E1	-8.970E0
241	✓	-1.561E2	7.833E1	6.889E1	8.611E1	-2.933E2	8.833E1	-2.222E2	-3.611E2	6.031E2	-1.817E1	-1.237E1
268	✓	-1.506E2	6.833E1	6.889E1	9.056E1	-2.933E2	8.167E1	-2.556E2	-3.722E2	7.364E2	-2.014E1	-1.795E1
290	✓	-1.561E2	7.833E1	6.889E1	9.500E1	-2.800E2	8.833E1	-2.111E2	-4.278E2	3.674E2	-1.267E1	-8.988E0
296	✓	-1.561E2	7.833E1	6.889E1	9.500E1	-2.933E2	9.500E1	-2.333E2	-4.056E2	5.529E2	-1.440E1	-9.446E0
320	✓	-1.561E2	6.167E1	6.333E1	8.611E1	-3.333E2	8.833E1	-2.111E2	-3.833E2	1.251E3	-2.879E1	-1.513E1
328	✓	-1.561E2	7.500E1	7.444E1	9.500E1	-2.800E2	8.833E1	-2.667E2	-4.056E2	4.740E2	-1.035E1	-1.091E1
342	✓	-1.506E2	7.500E1	7.444E1	9.500E1	-2.800E2	8.833E1	-2.222E2	-4.278E2	3.825E2	-8.050E0	-1.152E1
346	✓	-1.728E2	8.500E1	8.000E1	9.500E1	-2.800E2	8.833E1	-2.222E2	-3.944E2	3.907E2	-1.331E1	-8.458E0
380	✓	-1.617E2	8.167E1	6.889E1	8.611E1	-2.800E2	8.833E1	-2.333E2	-3.833E2	4.241E2	-1.418E1	-7.192E0
399	✓	-1.894E2	7.500E1	8.000E1	8.611E1	-3.067E2	9.500E1	-2.222E2	-3.944E2	7.740E2	-2.147E1	-9.570E0

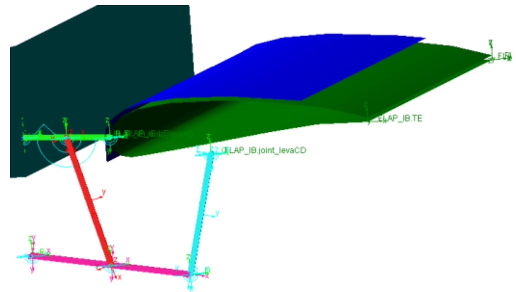


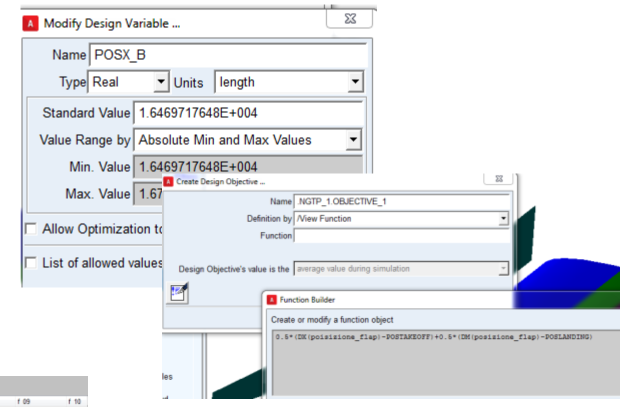


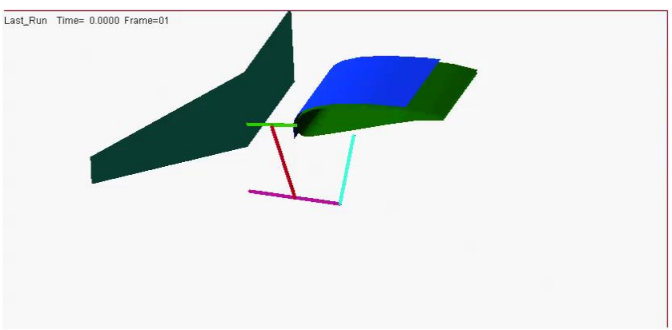
Flap model: Kinematic mechanism - 0.8











Work Space

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2	Trial 2	16746.8	5667.26	5500	5600	5780.23	16469.7	16762.2	16762.2	16762.2	[illegible]
3	Trial 3	16746.8	5667.26	5500	5600	5000	16746.8	16762.2	16762.2	16762.2	[illegible]
4	Trial 4	16746.8	5667.26	5500	5600	5000	16469.7	17638.8	16762.2	16762.2	[illegible]
5	Trial 5	16746.8	5667.26	5500	5600	5000	16469.7	16762.2	17638.8	16762.2	[illegible]
6	Trial 6	16746.8	5667.26	5500	5600	5000	16469.7	16762.2	16762.2	17638.8	[illegible]
7	Trial 7	16746.8	5667.26	5500	5600	5000	16469.7	16762.2	16762.2	16762.2	57
8	Trial 8	16469.7	6111.97	6111.97	5600	5000	16469.7	16762.2	16762.2	16762.2	[illegible]
9	Trial 9	16469.7	6111.97	5500	5780.23	5000	16469.7	16762.2	16762.2	16762.2	[illegible]
10	Trial 10	16469.7	6111.97	5500	5600	5780.23	16469.7	16762.2	16762.2	16762.2	[illegible]
11	Trial 11	16469.7	6111.97	5500	5600	5000	16746.8	16762.2	16762.2	16762.2	[illegible]
12	Trial 12	16469.7	6111.97	5500	5600	5000	16469.7	17638.8	16762.2	16762.2	[illegible]
13	Trial 13	16469.7	6111.97	5500	5600	5000	16469.7	16762.2	17638.8	16762.2	[illegible]
14	Trial 14	16469.7	6111.97	5500	5600	5000	16469.7	16762.2	16762.2	17638.8	[illegible]
15	Trial 15	16469.7	6111.97	5500	5600	5000	16469.7	16762.2	16762.2	16762.2	57
16	Trial 16	16469.7	5667.26	6111.97	5780.23	5000	16469.7	16762.2	16762.2	16762.2	[illegible]
17	Trial 17	16469.7	5667.26	6111.97	5600	5780.23	16469.7	16762.2	16762.2	16762.2	[illegible]
18	Trial 18	16469.7	5667.26	6111.97	5600	5000	16746.8	16762.2	16762.2	16762.2	[illegible]
19	Trial 19	16469.7	5667.26	6111.97	5600	5000	16469.7	17638.8	16762.2	16762.2	[illegible]
20	Trial 20	16469.7	5667.26	6111.97	5600	5000	16469.7	16762.2	17638.8	16762.2	[illegible]
21	Trial 21	16469.7	5667.26	6111.97	5600	5000	16469.7	16762.2	16762.2	16762.2	57
22	Trial 22	16469.7	5667.26	5500	5780.23	5780.23	16469.7	16762.2	16762.2	16762.2	[illegible]
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27	Trial 27	16469.7	5667.26	5500	5600	5780.23	16746.8	16762.2	16762.2	16762.2	[illegible]
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31	Trial 31	16469.7	5667.26	5500	5600	5000	16746.8	17638.8	16762.2	16762.2	[illegible]
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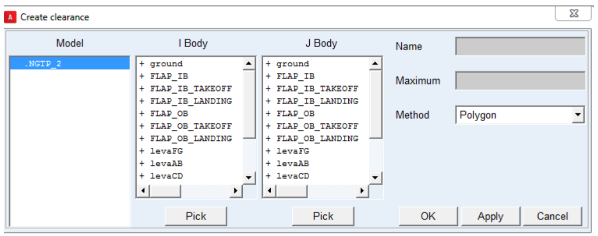

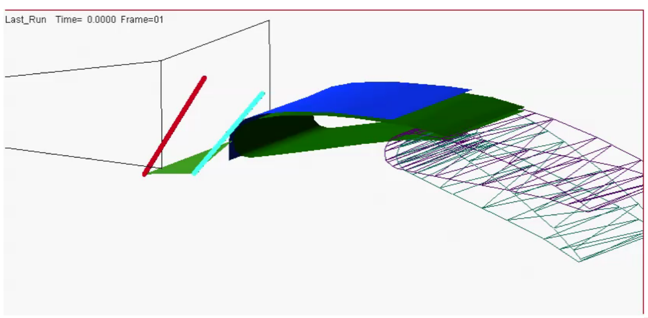

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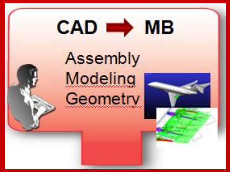
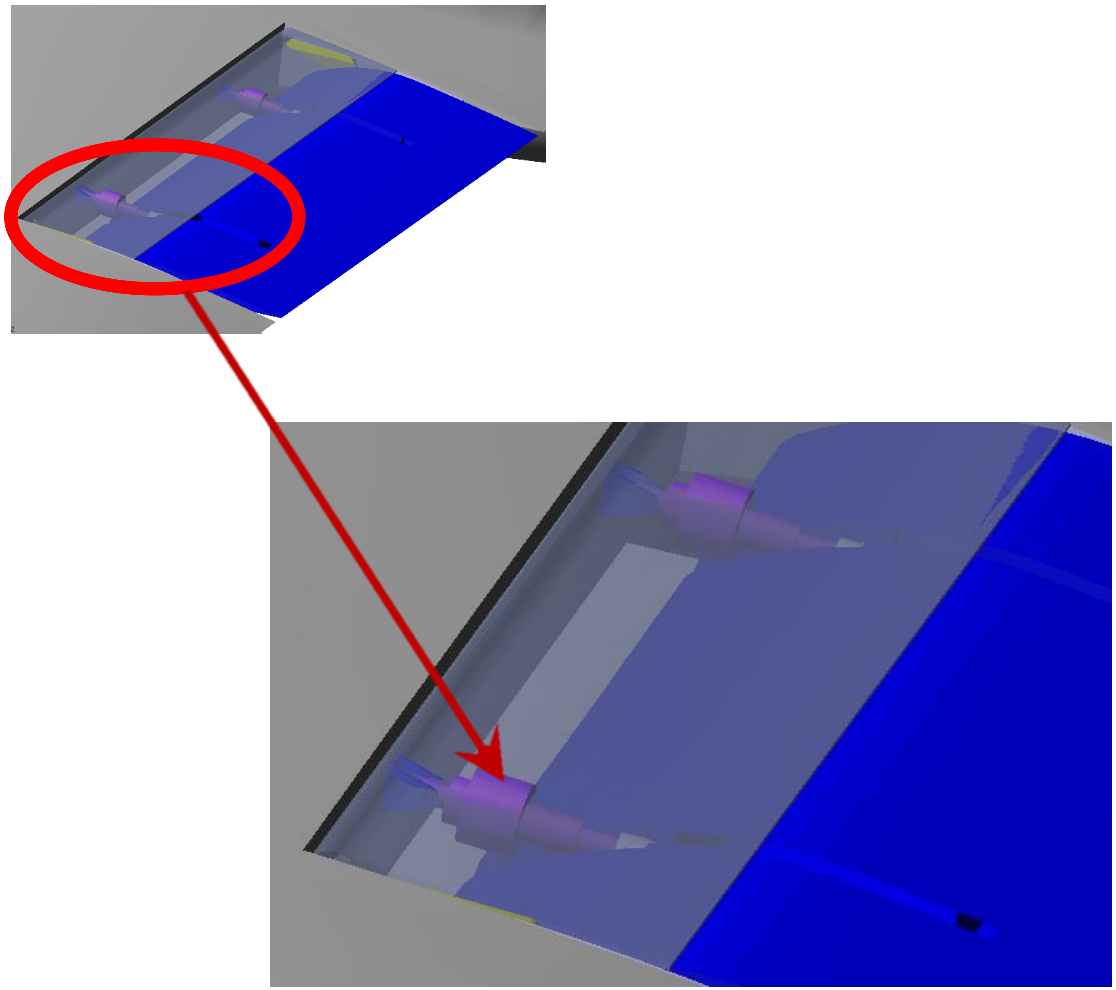
Flap model: Import 3D CAD –1.1

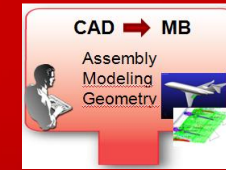


Flap System

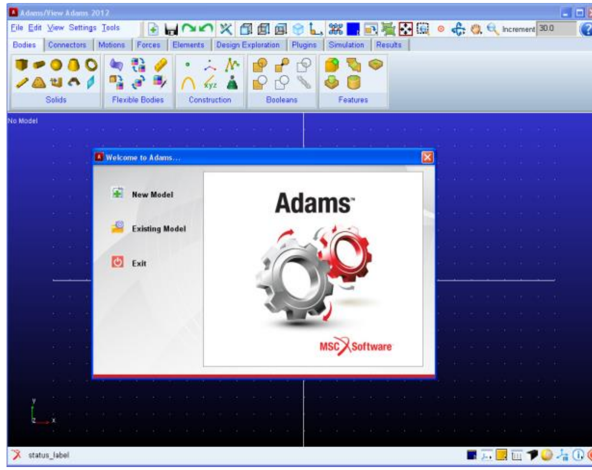
- Inboard flap
- dual screw drives
- driven by hydraulic, electric or hybrid motors



CAD – Multibody: CAD Interop. - 1.2



Adams/View
- Existing model
- File_Name = Flap_CAD.cmd



Shl files

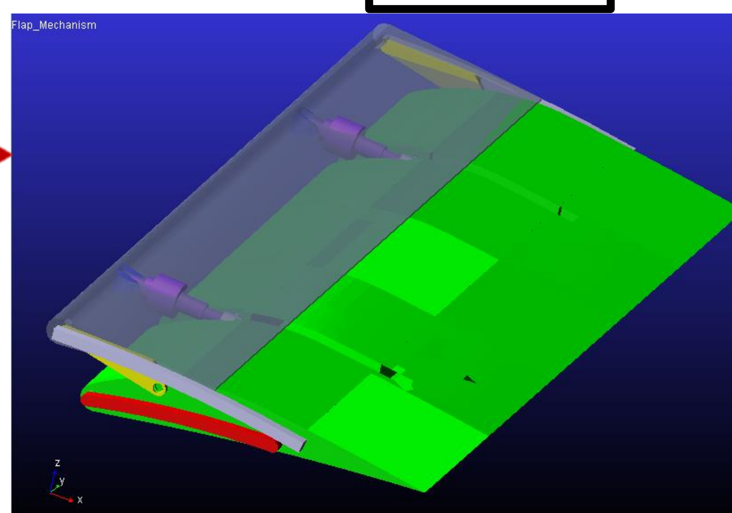
STEP file

Parasolid files

Markers for connections (joint, force) already derived from CAD coordinates)

Mass/Inertial/ CM from CAD or User

SPOILER



CURVEs, MATRICES already included (from CAD)

FLAP

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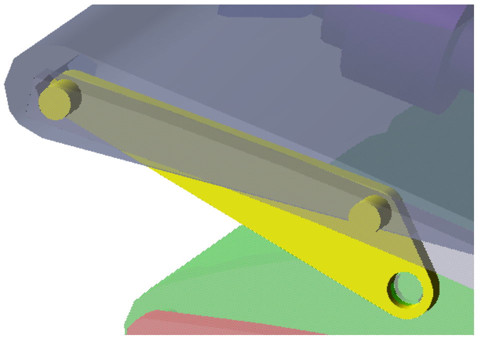
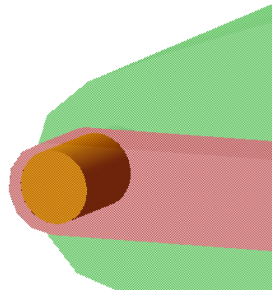
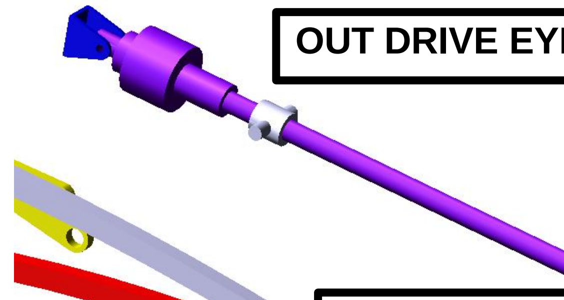
CAD – Multibody: CAD Interop. - 1.3



OUT SLIDER

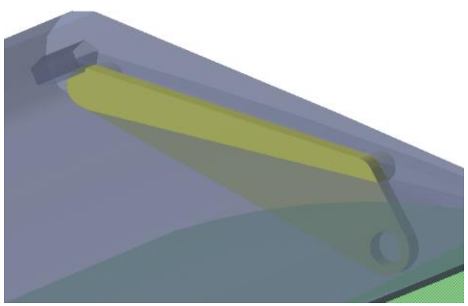


OUT BOT ROLLER

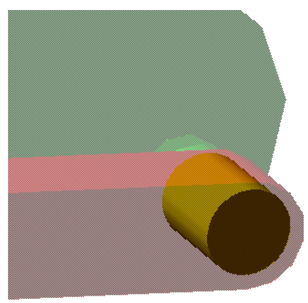


OUT DRIVE EYE

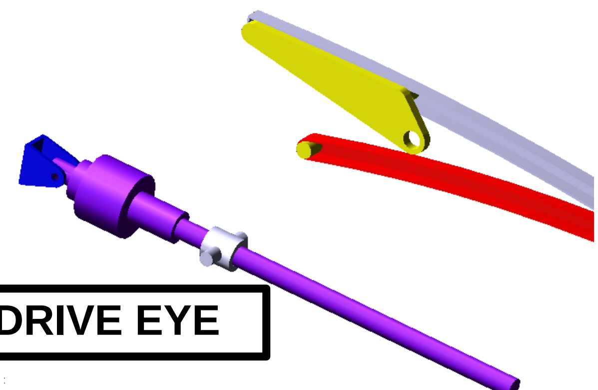
OUT DRIVE MOTOR



IN SLIDER



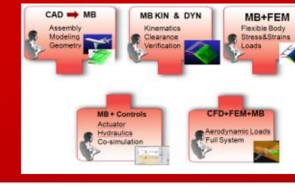
IN BOT ROLLER



IN DRIVE EYE

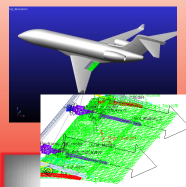
IN DRIVE MOTOR

Multidiscipline analysis



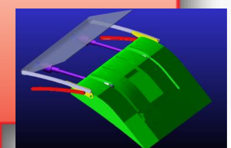
CAD ➡ MB

Assembly
Modeling
Geometry



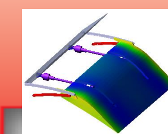
MB KIN & DYN

Adv. Kinematics
Clearance
Verification



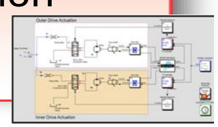
MB+FEM

Flexible Body
Stress&Strains
Loads



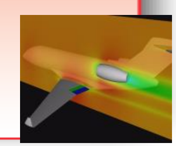
MB + Controls

Actuator
Hydraulics
Co-simulation



CFD+FEM+MB

Aerodynamic Loads
Full System



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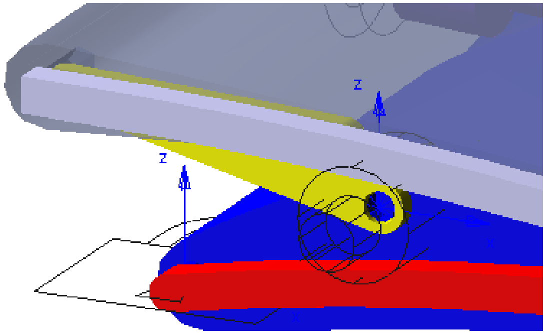
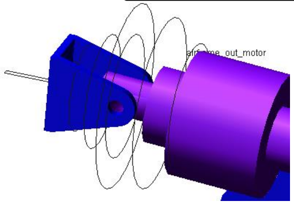
Multibody: Modeling, Topology - 2.1

Topology: constraints



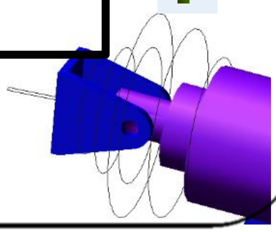
OUT BOT ROLLER / FLAP

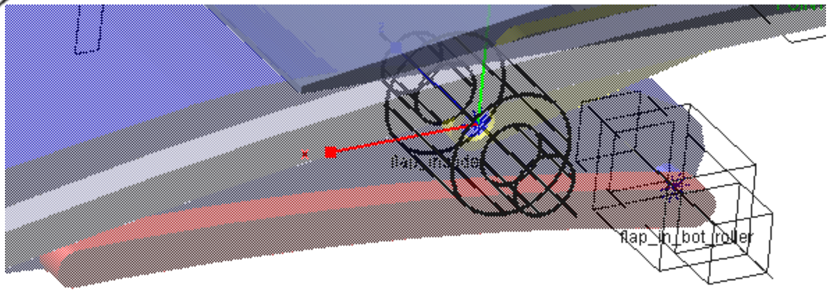
OUT SLIDER / FLAP



OUT DRIVE MOTOR/ AIRFRAME

IN DRIVE MOTOR/ AIRFRAME





IN SLIDER / FLAP

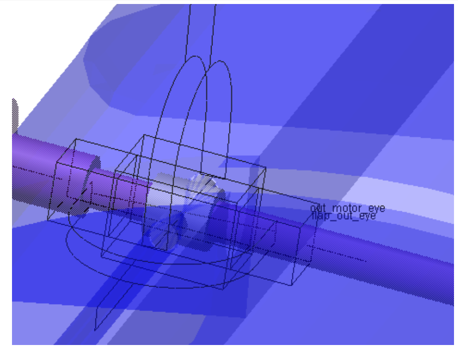
IN SLIDER / FLAP

Multibody: Modeling, Topology - 2.2

MB KIN & DYN
Kinematics
Clearance
Verification

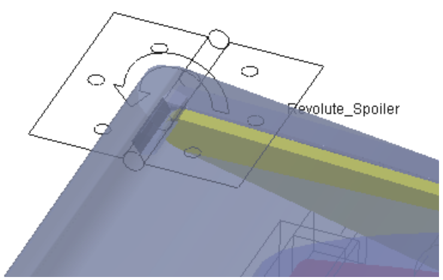
Topology: constraints

OUT DRIVE EYE/ FLAP

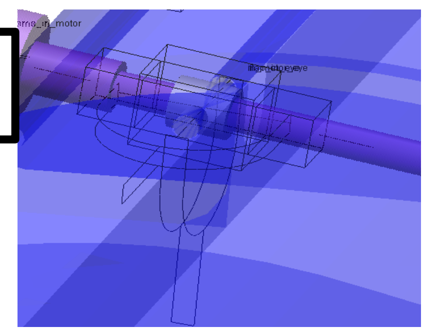


OUT DRIVE MOTOR/ DRIVE EYE

SPOILER/ AIRFRAME



IN DRIVE EYE/ FLAP



IN DRIVE MOTOR/ DRIVE EYE

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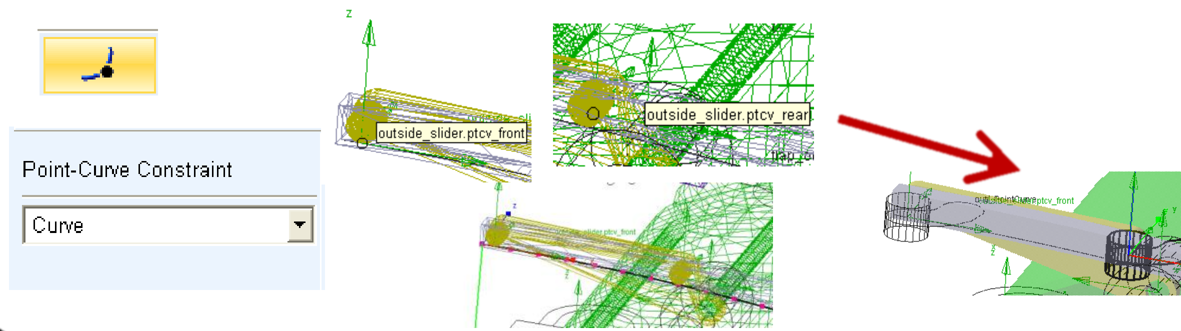
Multibody: Modeling, Topology - 2.3

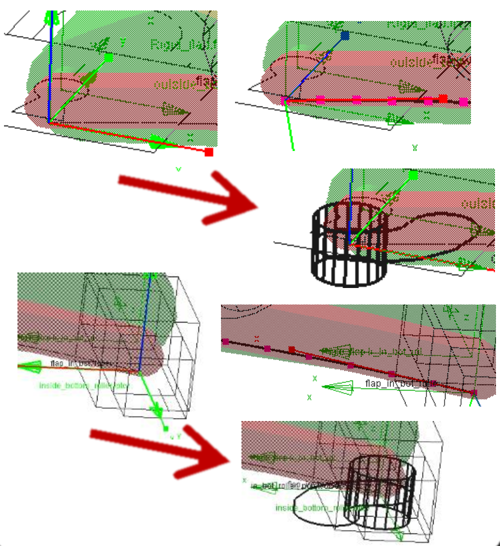
MB KIN & DYN
Kinematics
Clearance
Verification

Topology:
PTCV

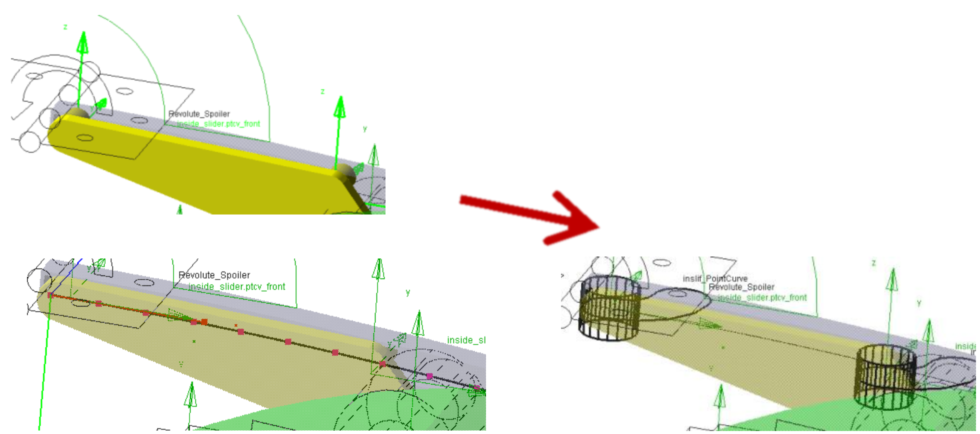
OUT SLIDER/AIRFRAME FRONT & REAR



IN & OUT BOTTOM ROLLER/ AIRFRAME



IN SLIDER/AIRFRAME FRONT & REAR



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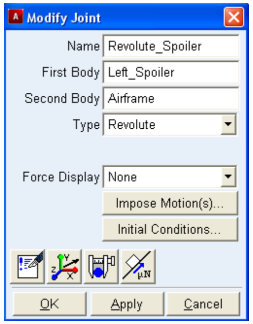
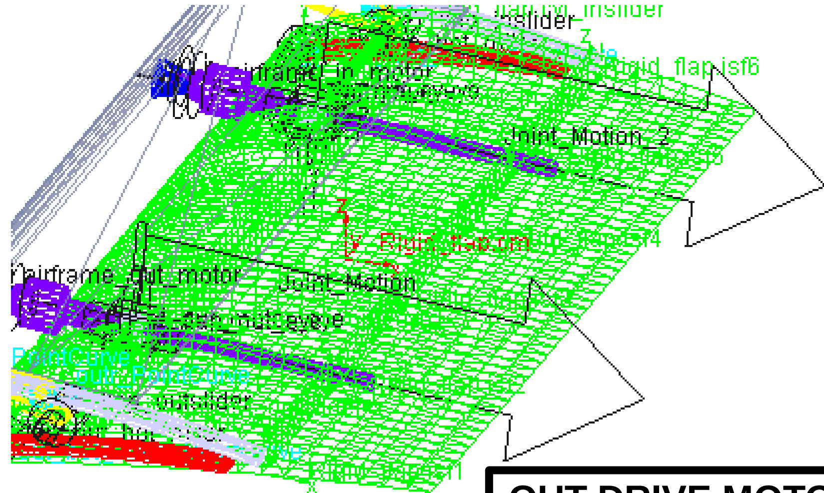
Multibody: Modeling, Topology - 2.4

Topology: Actuators

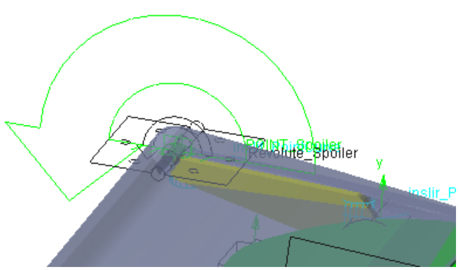


IN DRIVE MOTOR



OUT DRIVE MOTOR

SPOILER



STEP5(TIME,0,0,3,-0.44)

DTOR*(45*STEP5(TIME,5,0,7,1))

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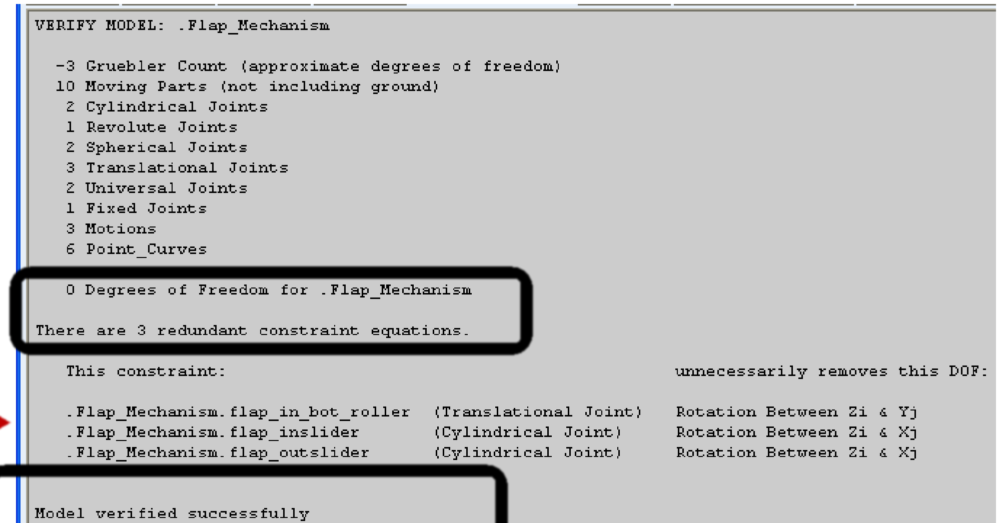
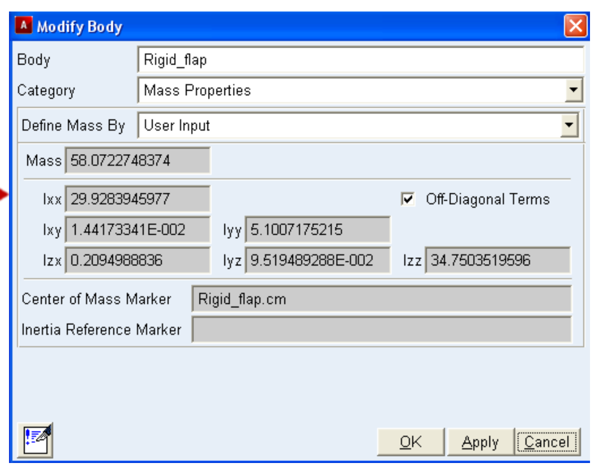
Multibody: Modeling, Topology - 2.5

Adams/View
- Existing model
- File_Name = Flap_Kin.cmd

Kinematic Model = 0 DOF

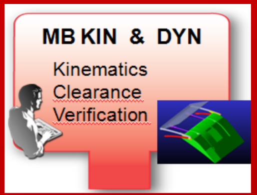


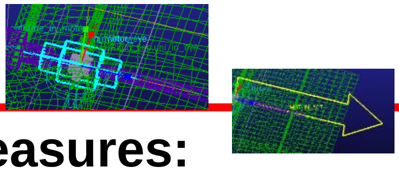
Mass & Inertia



Kinematic Analysis:
- Feasibility, functionality
- Actuator sizing
- Clearances
- failure

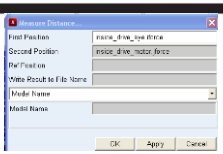
Multibody: Kinematic Analyis - 3.1





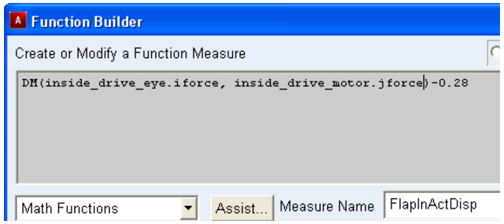
Measures:
Actuator
relative disp/vel/force

Dist. Iniziale



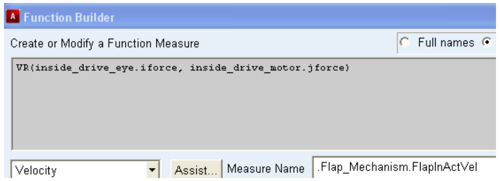
```
MAG = 0.2800486788 meter
X   = 0.2794 meter
Y   = 0.0 meter
Z   = -1.905E-002 meter
```

DM f(time)

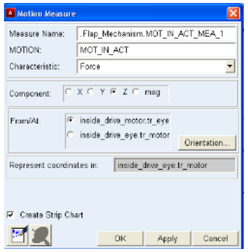


For In & Out Actuators

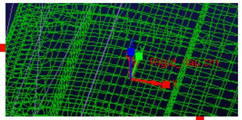
VR f(time)

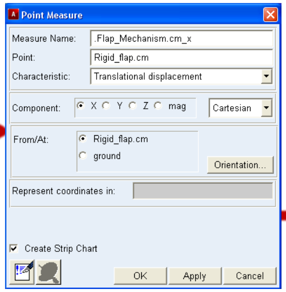


FZ f(time)



Measures:
Flap CM
global displacement





Kin Analysis
END =8 s
STEPS = 800

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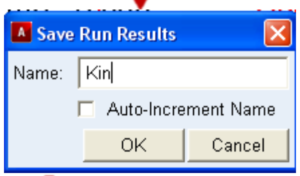
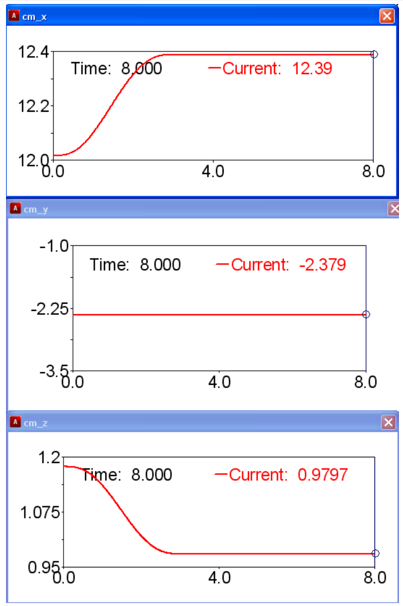
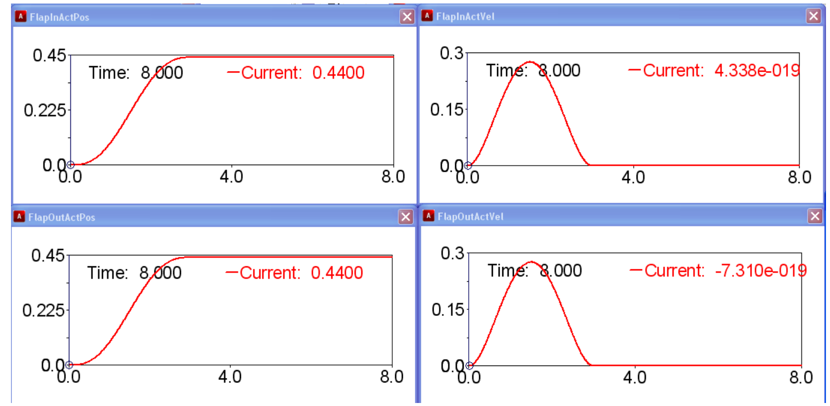
Multibody: Kinematic Analyis - 3.2

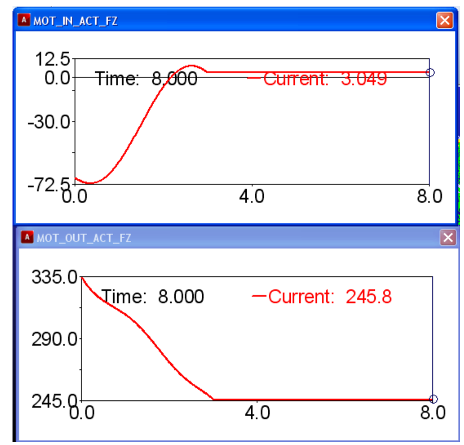
MB KIN & DYN
Kinematics
Clearance
Verification

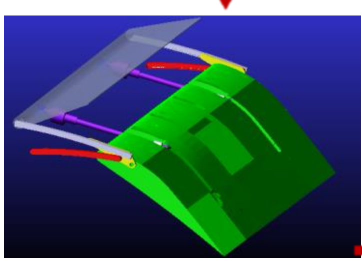
Kin Analysis
END =8 s
STEPS = 800

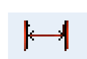




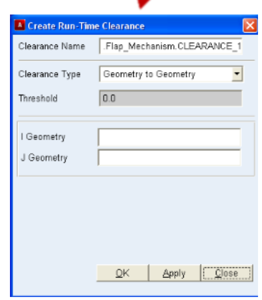




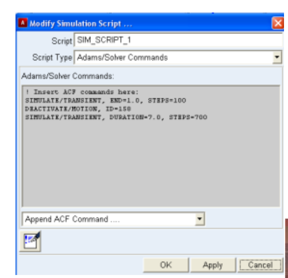




Clearance



Failure



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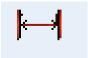
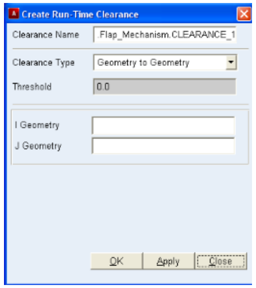
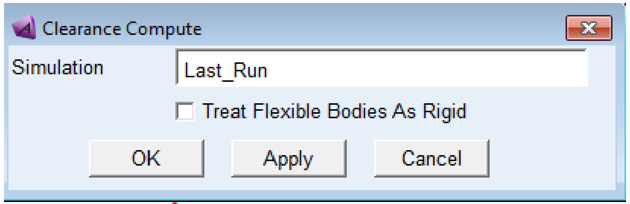
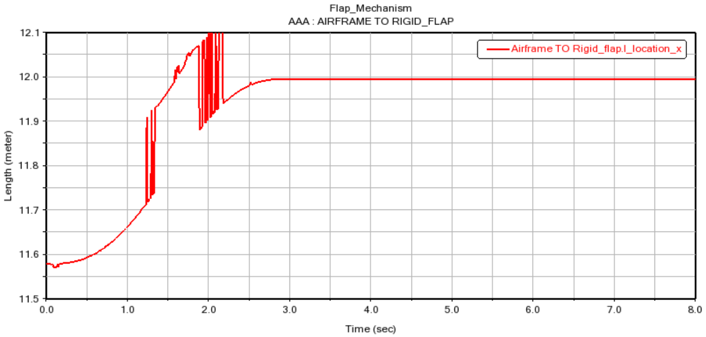
Multibody: Kinematic Analyis - 3.3

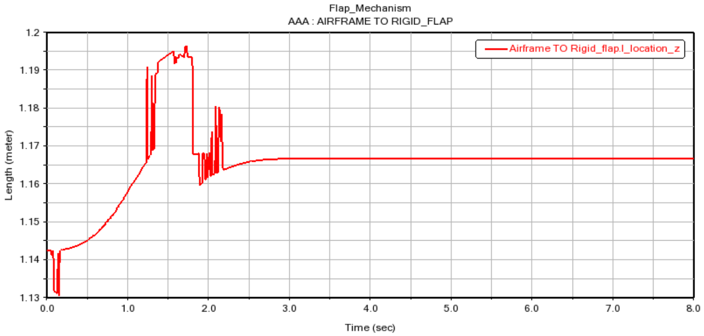
Clearance

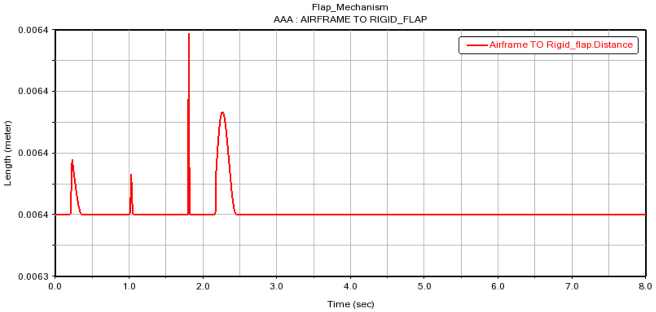






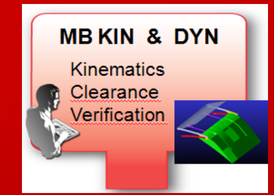




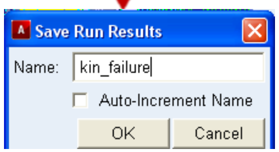


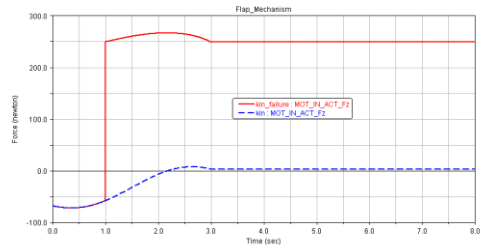
Files

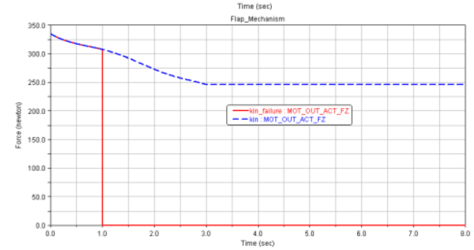
Multibody: Kinematic Analyis - 3.4

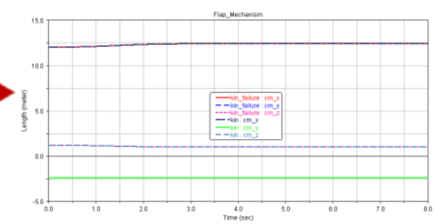


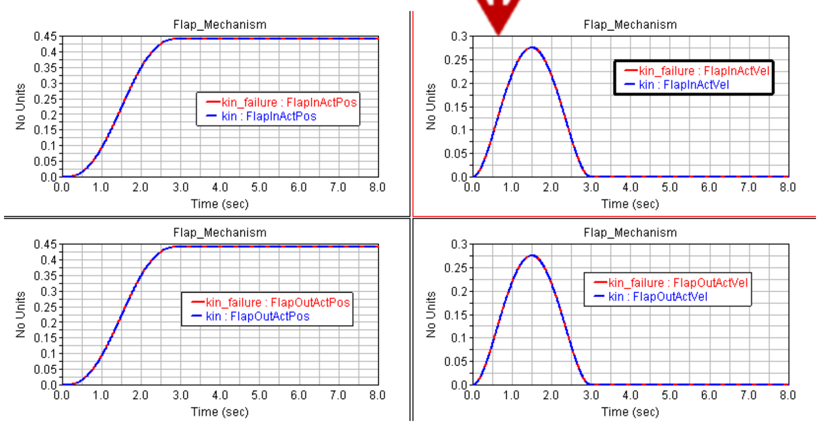
Failure Analysis
END =1 s, STEPS = 100
Deactivate/Motion, OutAct
DURATION=7 s, STEPS=700











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Multibody: Kinematic Analyis - 3.5

ADVs of kinematic model:

- easyness: rigid bodies model
- allows:
  - Functionality verification
  - Actuator sizing (preliminary)
  - Clearances analysis
  - failure

Limits:

- flap not flexible
- Ideal actuation (MOTION)
- No hydrualic model (or electric...=

Other capabilities:

- Aerodynamic forces on center of pressure to improve sizing and loads evaluation

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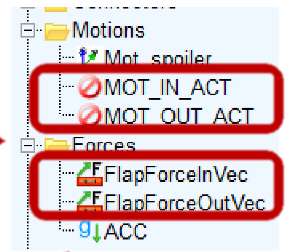
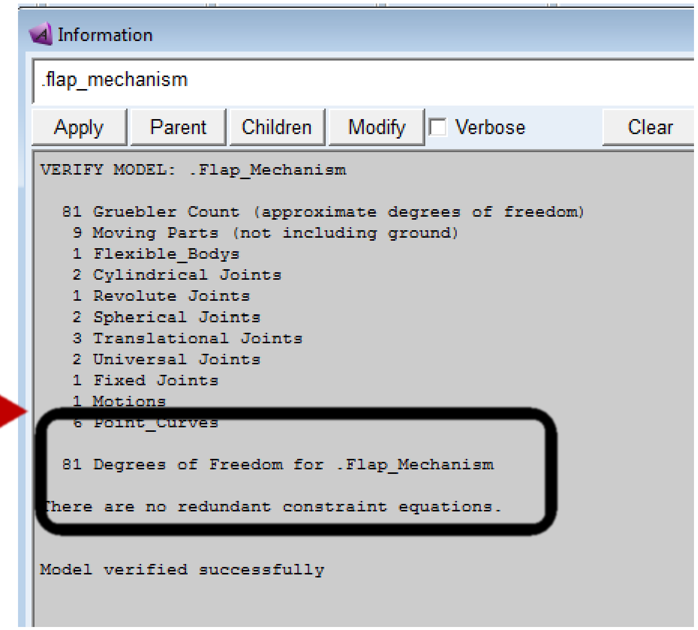
Multibody: Dynamic Analyis - 4.1

Adams/View
- **Existing model**
- **File_Name = Flap_DYN.cmd**

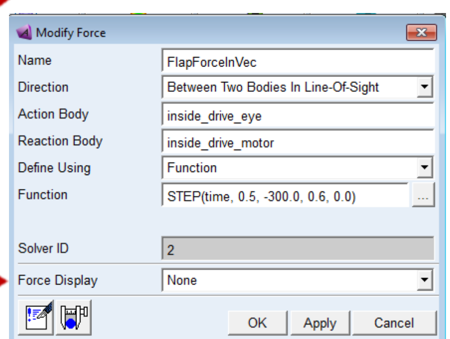


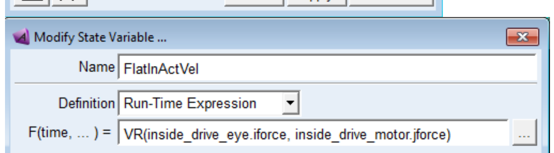
Dynamic Model = 81 DOFs



Forces

State Vars

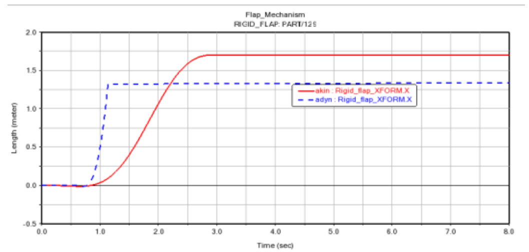


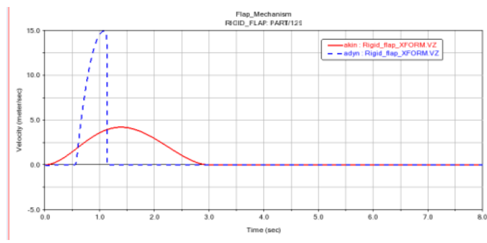


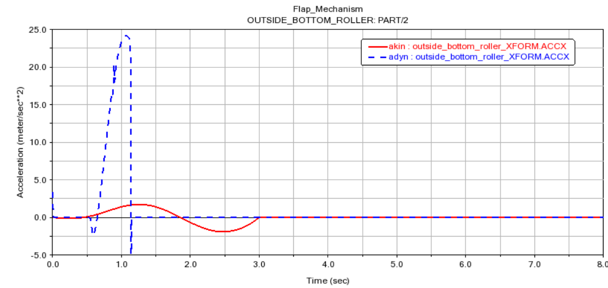
Dynamic Analysis:
- **verification**
- **Actuator sizing**
- **vibrations, damping**
- **failure**

Multibody: Dynamic Analyis –4.2

Comparison Kin/Dyn Analysis
END =8 s
STEPS = 800

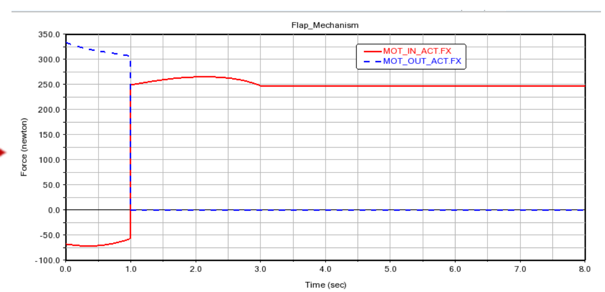


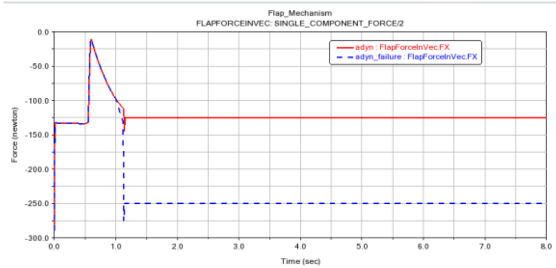




Comparison Failure Analysis

END =1 s, STEPS = 100
Deactivate/Force, OutAct
DURATION=7 s, STEPS=700





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Multibody: Dynamic Analyis - 4.3

MB KIN & DYN
Kinematics
Clearance
Verification

ADVs of dynamic model:

- «real» model
- Inertia effects
- Vibrations
- Failure
- Disturbances

Issues:

- increase of complexity, parameters, effort
- Requirement of more knowledge of physics

Other capabilities:

- Aerodynamic forces
- Hydraulic or electric or other model of actuators

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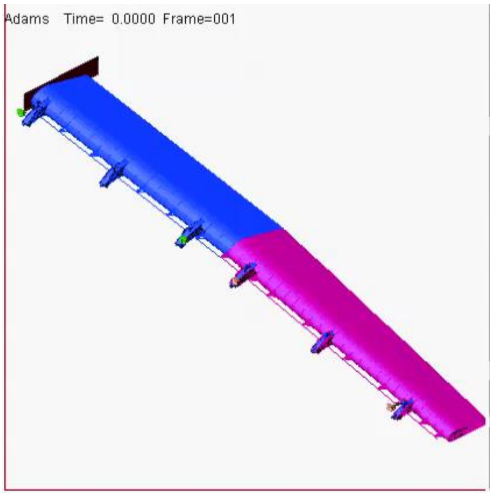
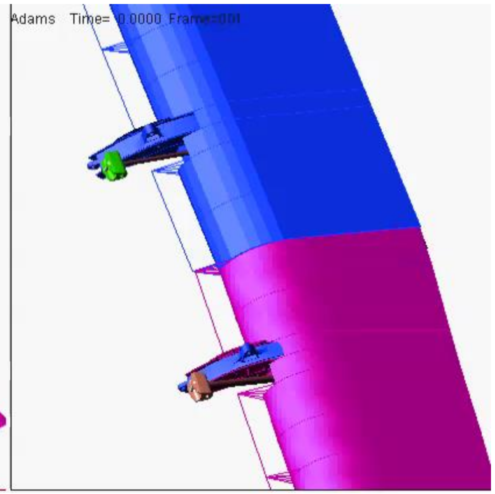
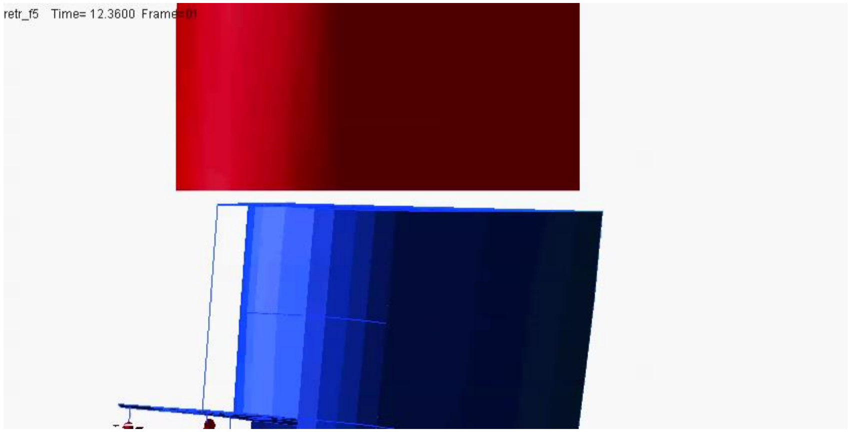
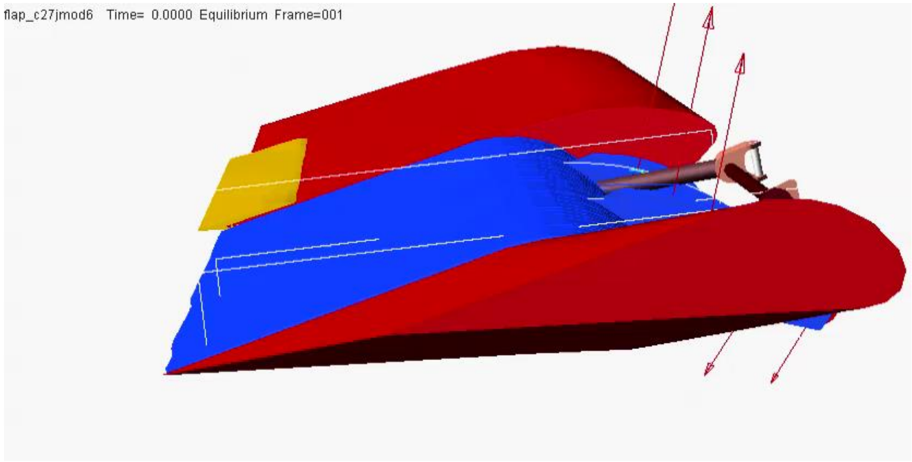
Multibody: Failure example - 4.4

MB KIN & DYN
Kinematics
Clearance
Verification









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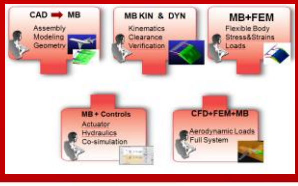
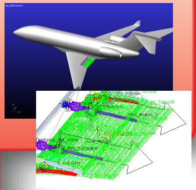
Multidiscipline analysis



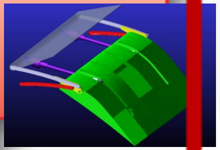
CAD ➡ MB

Assembly
Modeling
Geometry



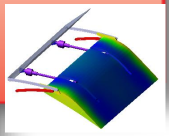
MB KIN & DYN

Adv. Kinematics
Clearance
Verification



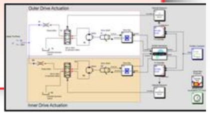
MB+FEM

Flexible Body
Stress&Strains
Loads



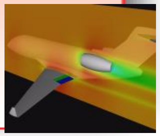
MB + Controls

Actuator
Hydraulics
Co-simulation



CFD+FEM+MB

Aerodynamic Loads
Full System



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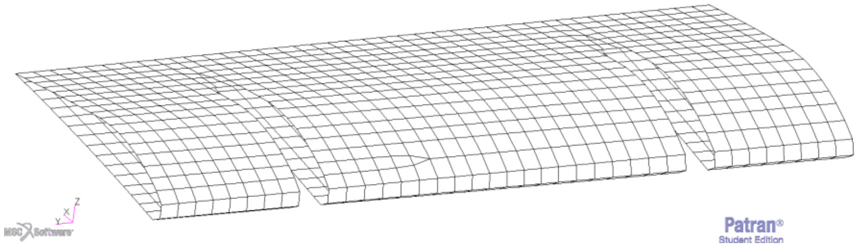
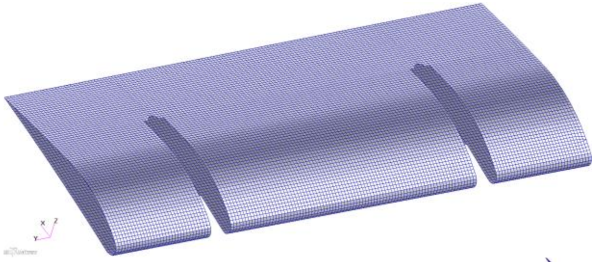
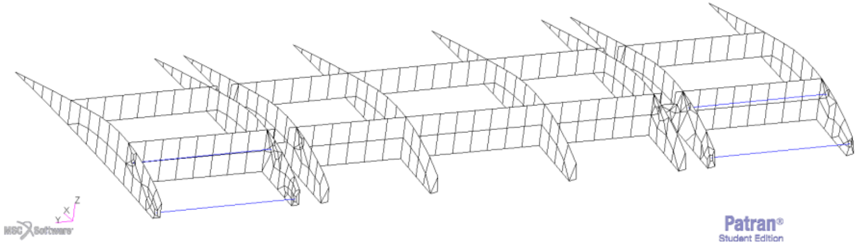
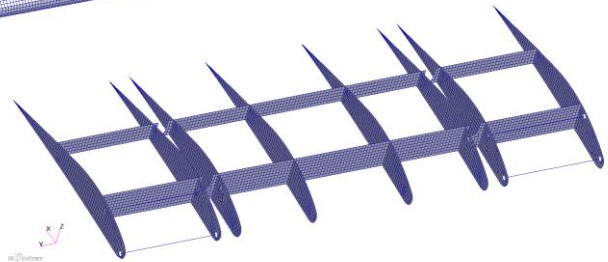
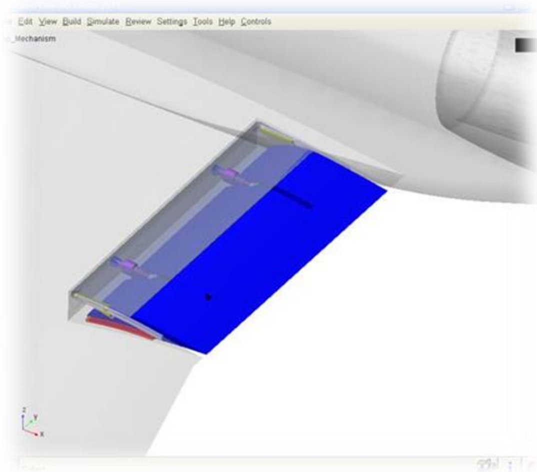
Meshing











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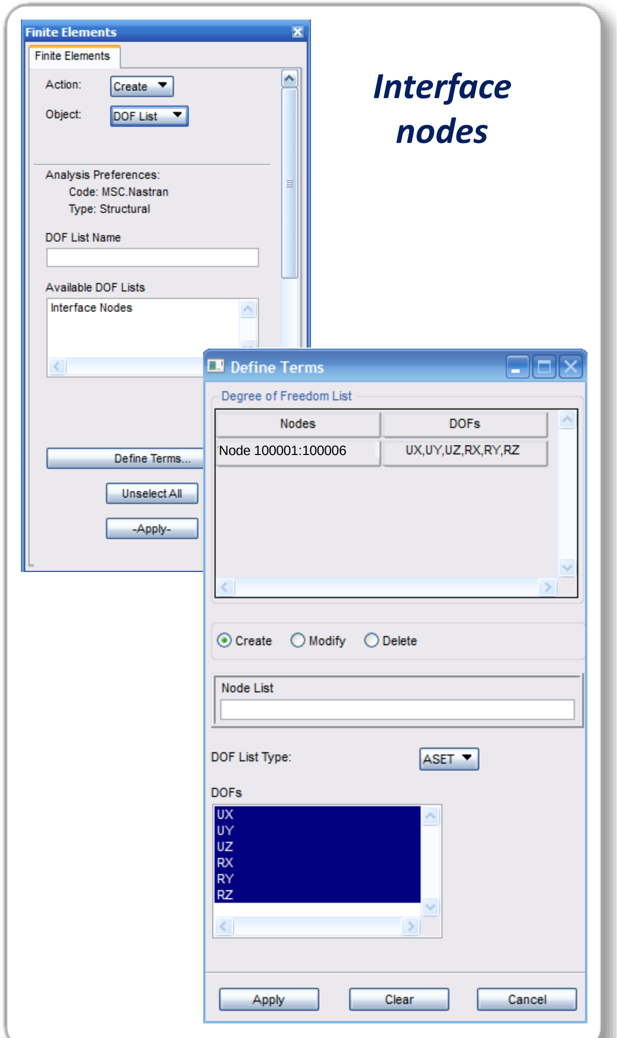
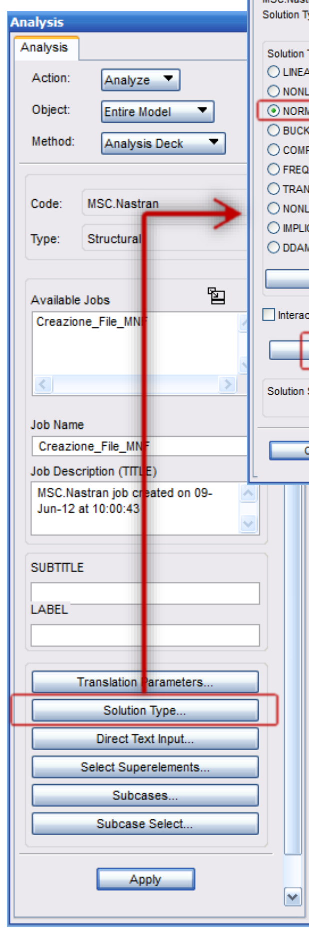
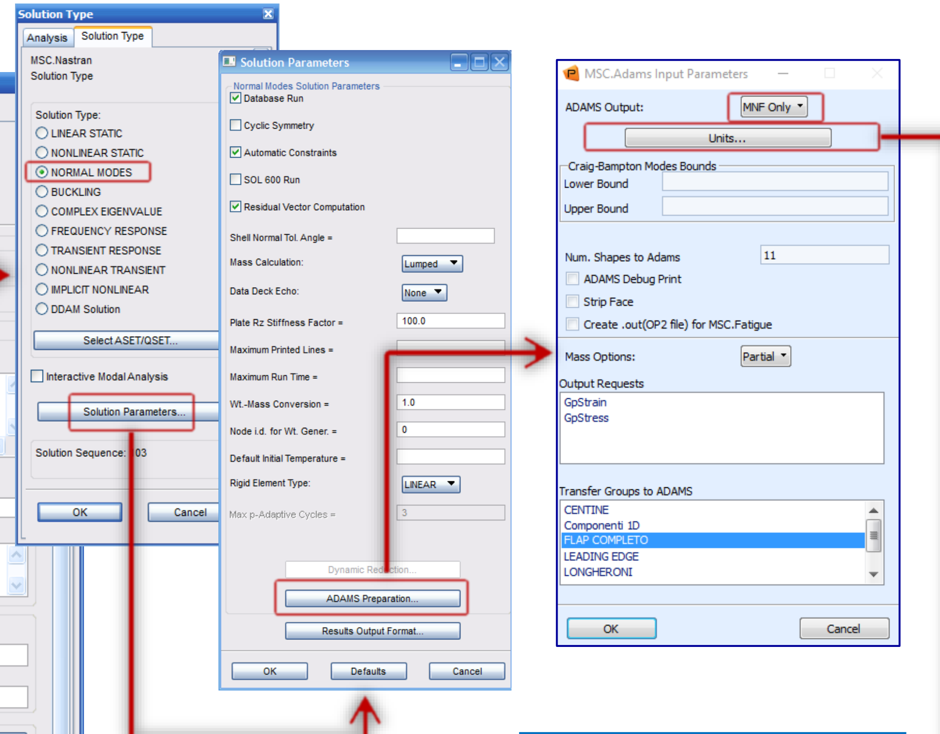
Analysis

Interface nodes







6 nodi·6 dofs = 36

+

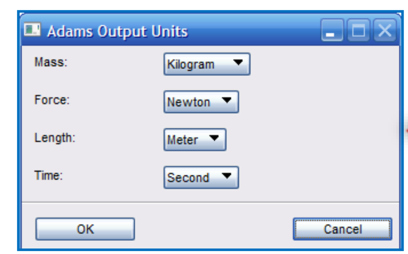
10 dynamic modes

+

1 modal load

=

47 modi free-free

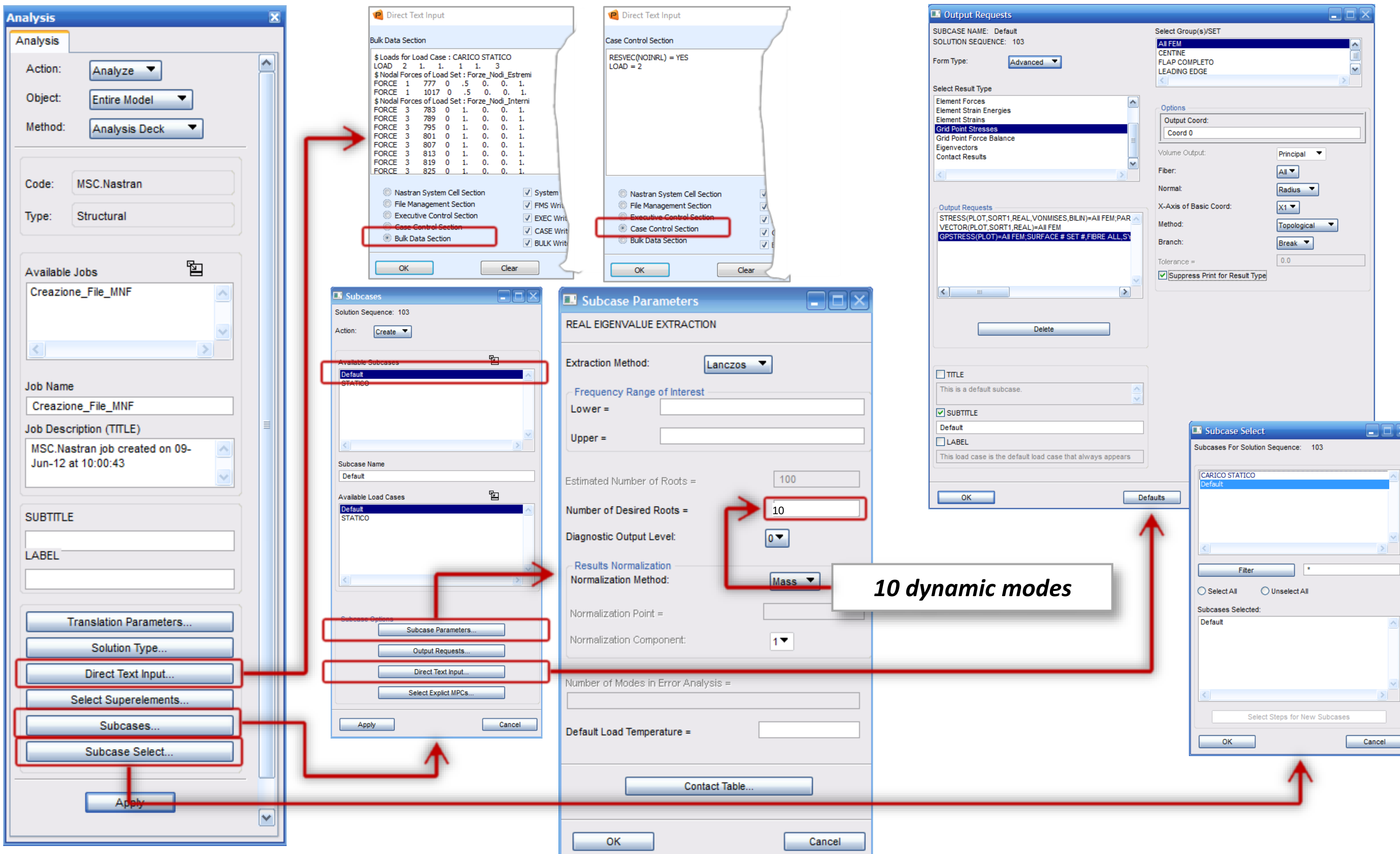


NODYCON 2021
Second International Nonlinear Dynamics Conference
February 16-19, 2021

MB+FEM
Flexible Body
Stress&Strains
Loads

MSC Nastran - Adams

Analysis



NODYCON 2021
Second International Nonlinear Dynamics Conference
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MSC Nastran - Adams

MB+FEM
Flexible Body
Stress&Strains
Loads

```
$ MSC.Nastran input file created on January   26, 2020 at 17:56:56 by
$ Patran 2019  (Student Edition)
$ Direct Text Input for Nastran System Cell Section
$ Direct Text Input for File Management Section
$ Direct Text Input for Executive Control
$ Normal Modes Analysis, Database
SOL 103
CEND
$ Direct Text Input for Global Case Control Data
RESVEC(NOINRL) = YES
LOAD = 2
TITLE = MSC.Nastran job created on 22-Jan-20 at 20:54:54
ECHO = NONE
$ Using Nastran default values for RESVEC
SET 1=2
ADAMSMNF FLEXBODY=YES,FLEXONLY=YES,PSETID=1
SUBCASE 1
   SUBTITLE=Default
$ Direct Text Input for this Subcase
   METHOD = 1
   VECTOR(SORT1,REAL)=ALL
   SPCFORCES(SORT1,REAL)=ALL
OUTPUT(POST)
$ Elements (and connectors) for group : FLAP COMPLETO
SET 2 = 1 THRU 1789,1790
BEGIN BULK
MDLPRM   HDF5    0
PARAM    PRTMAXIM YES
DTI      UNITS   1       KG      N       M       S
EIGRL    1                       10      0                       MASS
$ Elements and Element Properties for region : Pannelli
PSHELL   1       1       .004    1               1
$ Pset: "Pannelli" will be imported as: "pshell.1"
CQUAD4   1       1       1       2       11      10
CQUAD4   2       1       2       3       12      11
CQUAD4   3       1       3       4       13      12
...
CTRIA3   1461    3       1445    1451    1426
CTRIA3   1462    3       1451    1445    1448
$ Elements and Element Properties for region : Elementi_1D
PBARL    4       1               ROD
         .00635
$ Pset: "Elementi_1D" will be imported as: "pbarl.4"
CBAR     1759    4       1587    1588    0.      0.      1.
```

Creation of file MNF file

10 dynamic modes

```
CBAR     1760    4       1588    1589    0.      0.      1.
..
CBAR     1789    4       1620    1621    0.      0.      1.
CBAR     1790    4       1621    1622    0.      0.      1.
$ Referenced Material Records
$ Material Record : Alluminio
$ Description of Material : Date: 09-Jun-12          Time: 01:22:33
MAT1     1       7.+10           .33     2700.
$ Multipoint Constraints of the Entire Model
$ ID conflict : the PATRAN MPC ID was 1
RBE2     1791    100001  123456  1457    1458    1459    1468    1587
$ ID conflict : the PATRAN MPC ID was 2
...
$ ID conflict : the PATRAN MPC ID was 8
RBE2     1798    100004  123456  1542    1543    1544    1545    1555
         1556    1557    1558    16
$ Nodes of the Entire Model
GRID     1               12.18413-1.
GRID     2               12.18413-1.
...
GRID     100005          11.5824 -3.600451.1303
GRID     100006          11.7602 -3.603621.2192
$ Loads for Load Case : Default
SPOINT   100007  THRU    100017
QSET1            100007  THRU    100017
ASET1    123456  100001  100002  100003  100004  100005  100006
$ Referenced Coordinate Frames
$ Direct Text Input for Bulk Data
$ Loads for Load Case : CARICO STATICO
LOAD     2       1.      1.      1       1.      3
$ Nodal Forces of Load Set : Forze_Nodi_Estremi
FORCE    1       777     0       .5      0.      0.      1.
FORCE    1       1017    0       .5      0.      0.      1.
$ Nodal Forces of Load Set : Forze_Nodi_Interni
FORCE    3       783     0       1.      0.      0.      1.
FORCE    3       789     0       1.      0.      0.      1.
...
FORCE    3       1005    0       1.      0.      0.      1.
FORCE    3       1011    0       1.      0.      0.      1.
ENDDATA 59f4f666
```

11 modes including 1 Residual Vector

6 interface nodes

Modal Force

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MSC Nastran - Adams

REAL EIGENVALUES
(BEFORE AUGMENTATION OF RESIDUAL VECTORS)

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	2.836929E+05	5.326283E+02	8.477043E+01	1.000000E+00	2.836929E+05
2	2	7.074947E+05	8.411270E+02	1.338695E+02	1.000000E+00	7.074947E+05
...						
9	9	1.626282E+06	1.27525			
10	10	1.641885E+06	1.28136			

REAL EIGENVALUES
(AFTER AUGMENTATION OF RESIDUAL VECTORS)

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	2.836929E+05	5.326283E+02	8.477043E+01	1.000000E+00	2.836929E+05
2	2	7.074947E+05	8.411270E+02	1.338695E+02	1.000000E+00	7.074947E+05
...						
9	9	1.626282E+06	1.275258E+03	2.029635E+02	1.000000E+00	1.626282E+06
10	10	1.641885E+06	1.281360E+03	2.039348E+02	1.000000E+00	1.641885E+06
11	11	4.005155E+06	2.001288E+03	3.185149E+02	1.000000E+00	4.005155E+06

```
^^^
^^^   NASTRAN/ADAMS INTERFACE DMAP INFORMATION MESSAGE:
^^^
^^^   READ MODULE IS BEING USED FOR A-SET ORTHONORMALIZATION
^^^
*** USER INFORMATION MESSAGE 5458 (REIG)
    QL HOUSEHOLDER METHOD IS AUTOMATICALLY SELECTED .
^^^
^^^   NASTRAN/ADAMS INTERFACE DMAP INFORMATION MESSAGE:
^^^
^^^   DURING A-SET ORTHONORMALIZATION,
^^^   A TOTAL OF    47          MODES WERE FOUND
^^^   OUT OF A POSSIBLE    47          .
^^^
```

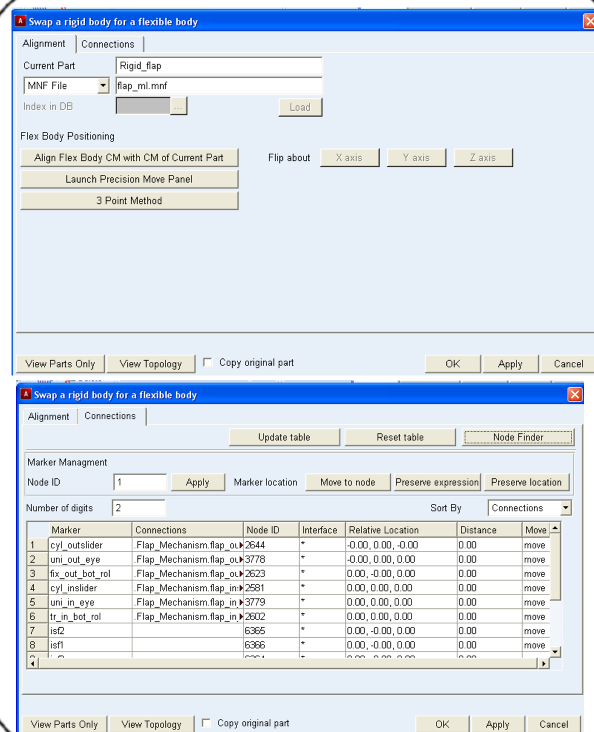
6 nodi·6 dofs = 36
+
10 modes
+
1 modal load
=
47 modi free-free

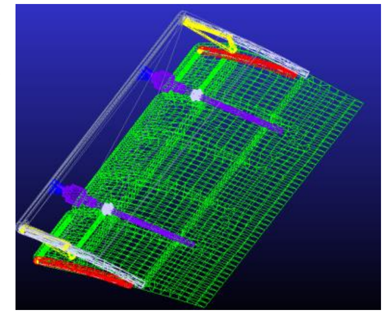
REAL EIGENVALUES

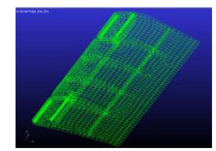
MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	-1.344368E-07	3.666562E-04	5.835514E-05	1.000000E+00	-1.344368E-07
2	2	-7.663624E-08	2.768325E-04	4.405926E-05	1.000000E+00	-7.663624E-08
3	3	-2.717132E-08	1.648373E-04	2.623466E-05	1.000000E+00	-2.717132E-08
4	4	5.208844E-08	2.282289E-04	3.632376E-05	1.000000E+00	5.208844E-08
5	5	9.702277E-08	3.114848E-04	4.957434E-05	1.000000E+00	9.702277E-08
6	6	1.967302E-07	4.435428E-04	7.059203E-05	1.000000E+00	1.967302E-07
7	7	3.920560E+05	6.261437E+02	9.965387E+01	1.000000E+00	3.920560E+05
...						
42	42	5.041897E+08	2.245417E+04	3.573692E+03	1.000000E+00	5.041897E+08
43	43	5.132132E+08	2.265421E+04	3.605529E+03	1.000000E+00	5.132132E+08
44	44	1.439797E+09	3.794465E+04	6.039079E+03	1.000000E+00	1.439797E+09
45	45	1.462010E+09	3.823624E+04	6.085486E+03	1.000000E+00	1.462010E+09
46	46	6.097180E+09	7.808444E+04	1.242752E+04	1.000000E+00	6.097180E+09
47	47	7.726424E+09	8.790008E+04	1.398973E+04	1.000000E+00	7.726424E+09

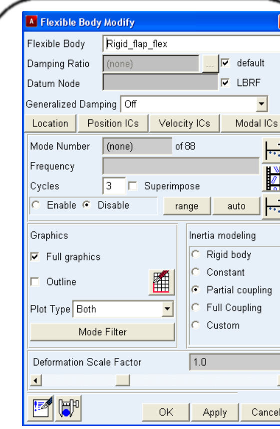
Multibody: Flexible Body – 6.1

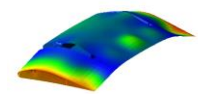
Rigid to Flex

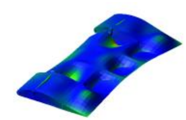






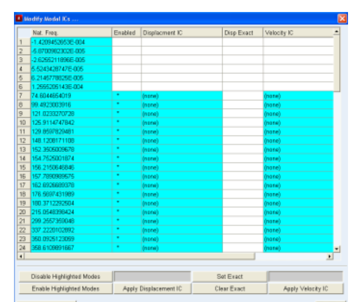




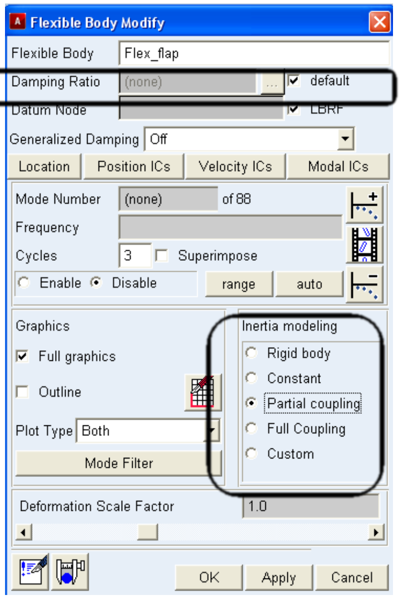


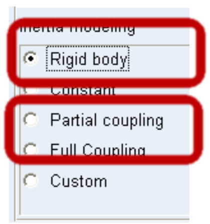
```
VERIFY MODEL: .Flap_Mechanism

  79 Gruebler Count (approximate degrees of freedom)
   9 Moving Parts (not including ground)
   1 Flexible_Bodys
   2 Cylindrical Joints
   1 Revolute Joints
   2 Spherical Joints
   3 Translational Joints
   2 Universal Joints
   1 Fixed Joints
   3 Motions

  79 Degrees of Freedom for .Flap_Mechanism

There are no redundant constraint equations.

Model verified successfully
```

Dynamic Model

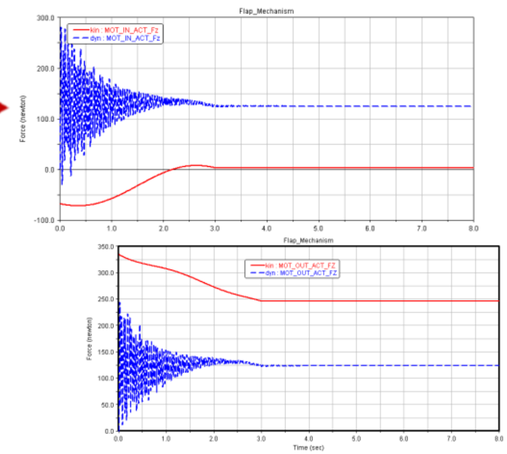


Multibody: Flexible Body – 6.2



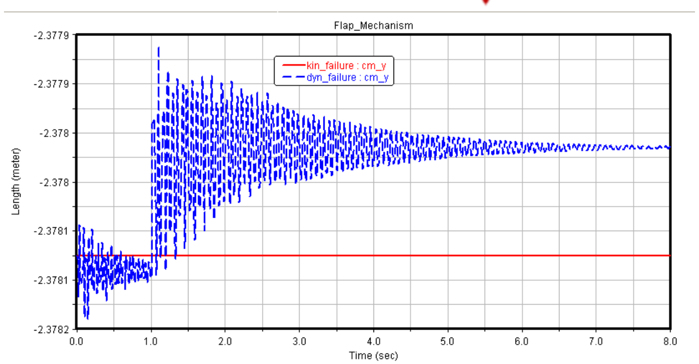


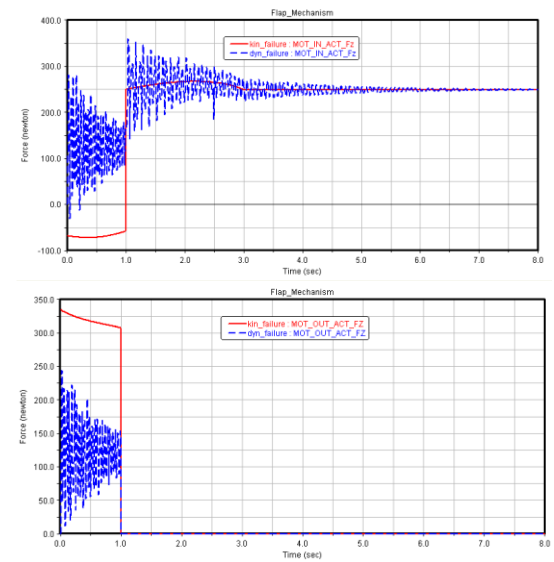
Comparison Rig/Flex Analysis
END =8 s
STEPS = 800

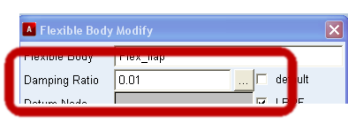


Comparison Failure Analysis

END =1 s, STEPS = 100
Deactivate/Motion, OutAct
DURATION=7 s, STEPS=700



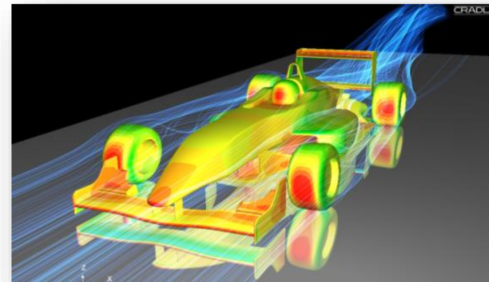


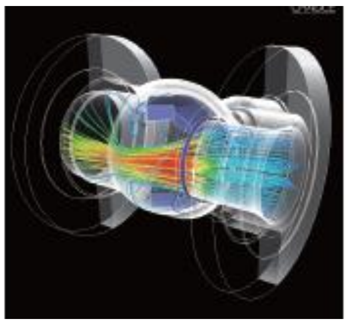


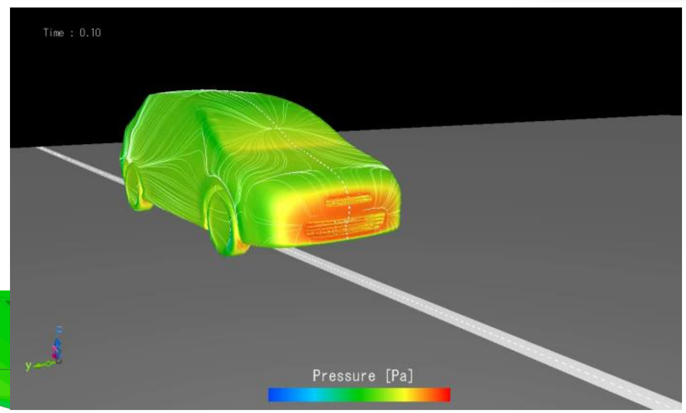
***Damping values, comparison**

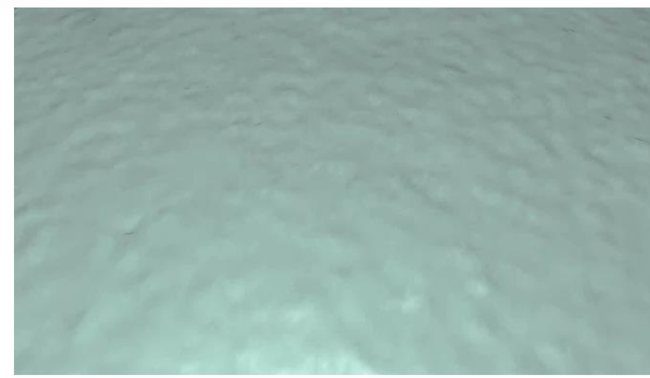
CFD: Aerodynamic Force (notes) 7.1

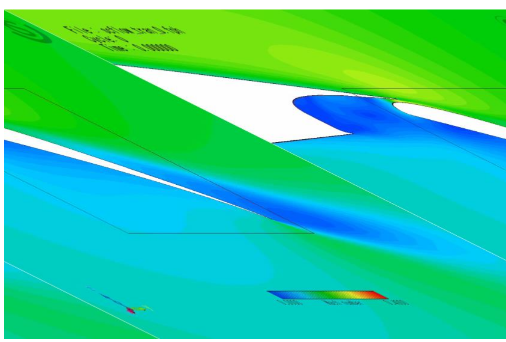
Cradle
MSC Software Company

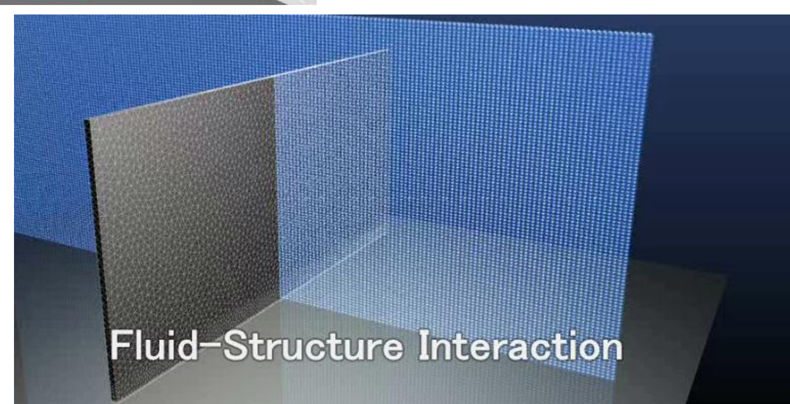












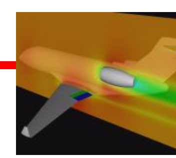
CFD: Aerodynamic Force (notes) 7.2

CFD+FEM+MB
Aerodynamic Loads
Full System

Many config → **α β δ Mach** → Cradle (MSC Software Company) → **PLOAD FORCE**

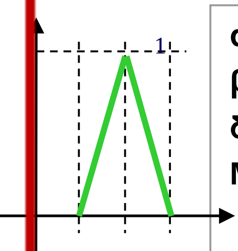
SUBCASE 1
LABEL= Mach=0.350000, Alfa=8.000000, Beta=0.000000, Delta=0.000000
LOAD = 1

→ **NASTRAN** → **MNF with Modal Loads** → **ADAMS MFORCE**



Aero Map Scaling factors

FUNCTION OF:



α β δ Mach.

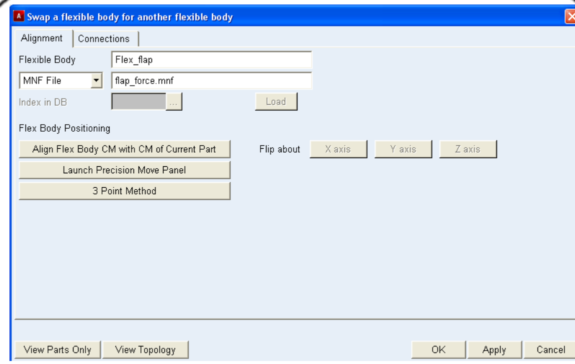
and

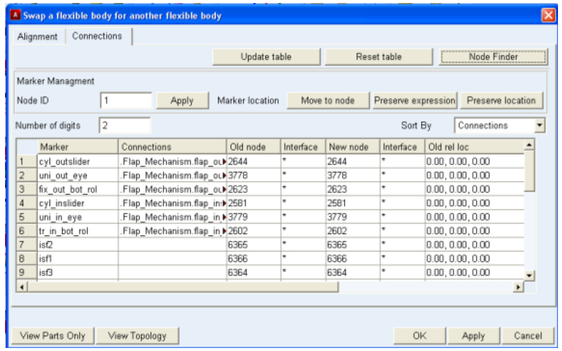
D **α β δ Mach** /DT

D^2 **α β δ Mach** $/DT^2$

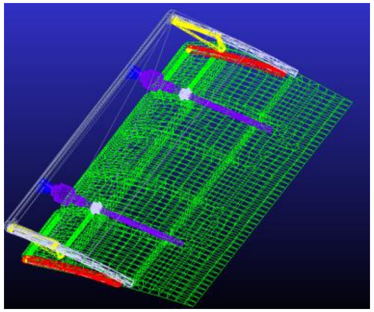
Multibody: FlexBody and Aero Forces – 8.1

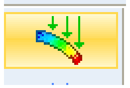
Flex to Flex



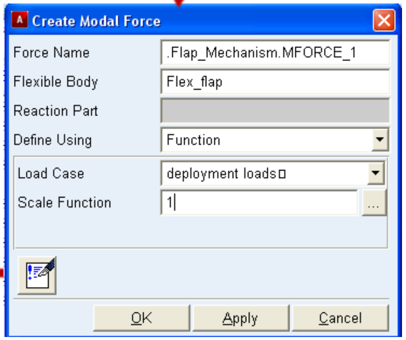


	Marker	Connections	Old node	Interface	New node	Interface	Old rel loc
1	cyl_outslider	.Flap_Mechanism.flap_ou	2644	*	2644	*	0.00, 0.00, 0.00
2	uni_out_eye	.Flap_Mechanism.flap_ou	3778	*	3778	*	0.00, 0.00, 0.00
3	fix_out_bot_rol	.Flap_Mechanism.flap_ou	2623	*	2623	*	0.00, 0.00, 0.00
4	cyl_inslider	.Flap_Mechanism.flap_in	2581	*	2581	*	0.00, 0.00, 0.00
5	uni_in_eye	.Flap_Mechanism.flap_in	3779	*	3779	*	0.00, 0.00, 0.00
6	tr_in_bot_rol	.Flap_Mechanism.flap_in	2602	*	2602	*	0.00, 0.00, 0.00
7	isf2		6365	*	6365	*	0.00, 0.00, 0.00
8	isf1		6366	*	6366	*	0.00, 0.00, 0.00
9	isf3		6364	*	6364	*	0.00, 0.00, 0.00

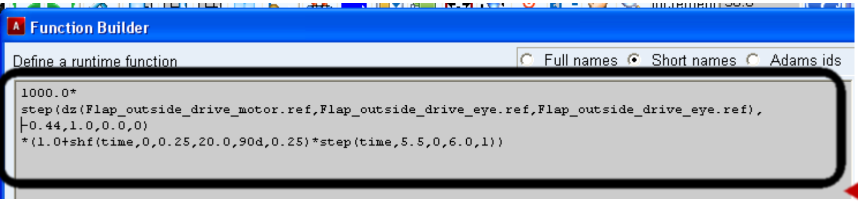




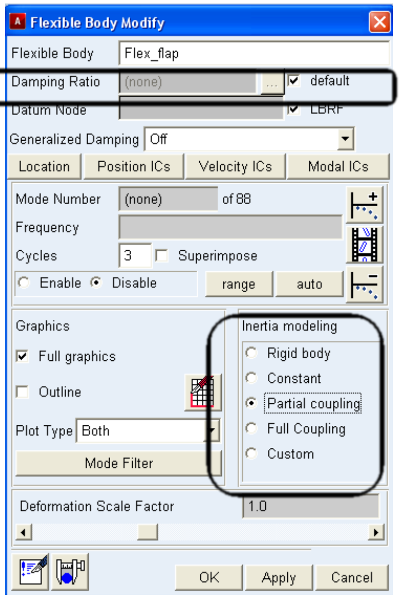
Modal Force

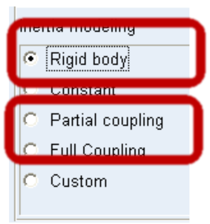


Scale:
- **-f(time)**
- **-f(δ flap)**
- **-f(rot spoiler)**
- **-f(speed)**
- **-f(Mach)**

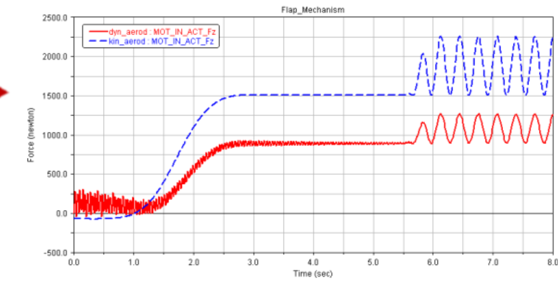


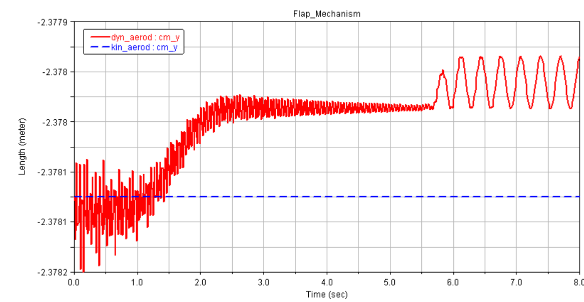
Multibody: FlexBody and Aero Forces – 8.2

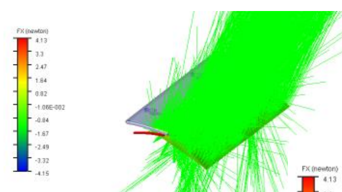


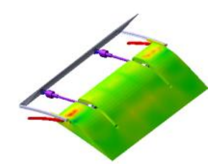


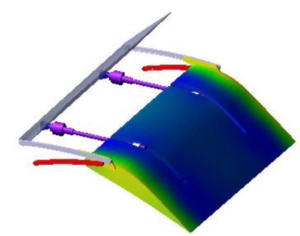
Comparison
Rig/Flex Analysis
END =8 s
STEPS = 800





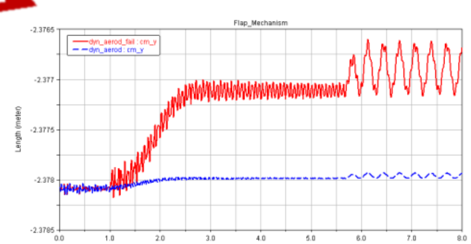






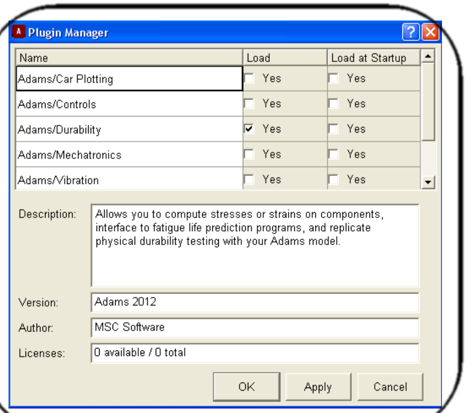
Comparison
Failure Analysis with and w/o aerodynamic force

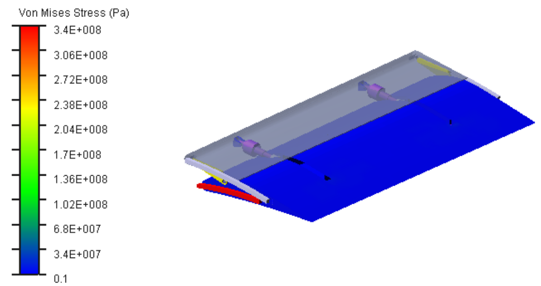
END =1 s, STEPS = 100
Deactivate/Motion, OutAct
DURATION=7 s, STEPS=700



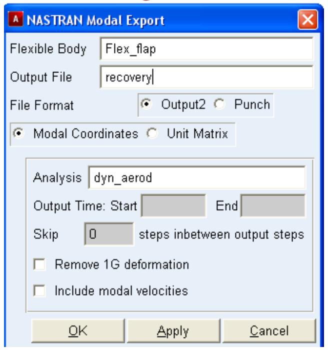
Multibody: Stress recovery (notes) - 9.1

Durability

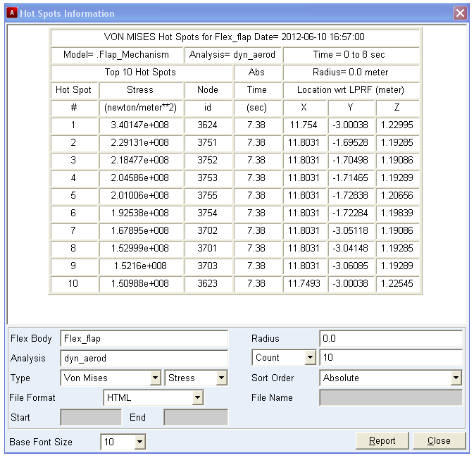




Output to Nastran: MDF

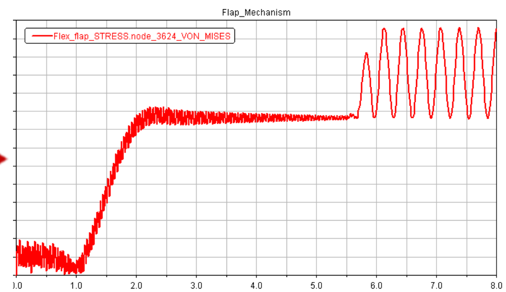


Hot Spot table



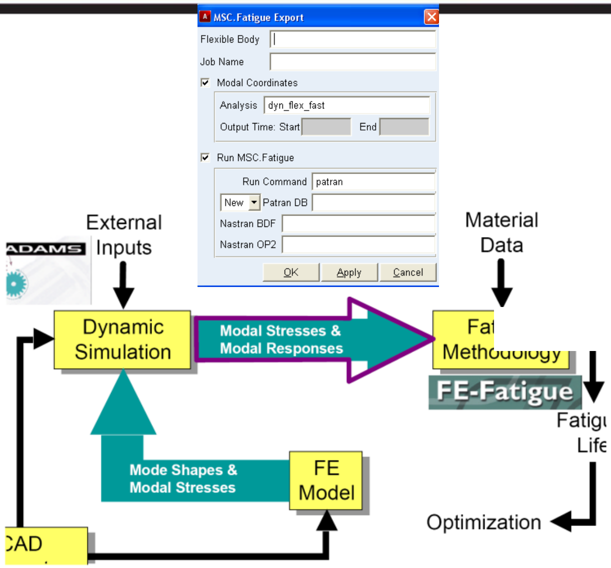
VON MISES Hot Spots for Flex_flap Date= 2012-06-10 16:57:00						
Model= .Flap_Mechanism		Analysis= dyn_aerod		Time = 0 to 8 sec		
Top 10 Hot Spots			Abs	Radius= 0.0 meter		
Hot Spot	Stress	Node	Time	Location wrt LPRF (meter)		
#	(newton/meter**2)	id	(sec)	X	Y	Z
1	3.40147e+008	3624	7.38	11.754	-3.00038	1.22995
2	2.29131e+008	3751	7.38	11.8031	-1.69528	1.19285
3	2.18477e+008	3752	7.38	11.8031	-1.70498	1.19086
4	2.04586e+008	3753	7.38	11.8031	-1.71465	1.19289
5	2.01006e+008	3755	7.38	11.8031	-1.72838	1.20656
6	1.92538e+008	3754	7.38	11.8031	-1.72284	1.19839
7	1.67895e+008	3702	7.38	11.8031	-3.05118	1.19086
8	1.52999e+008	3701	7.38	11.8031	-3.04148	1.19285
9	1.5216e+008	3703	7.38	11.8031	-3.06085	1.19289
10	1.50988e+008	3623	7.38	11.7493	-3.00038	1.22545

Nodal Stresses Plot

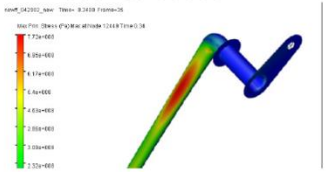


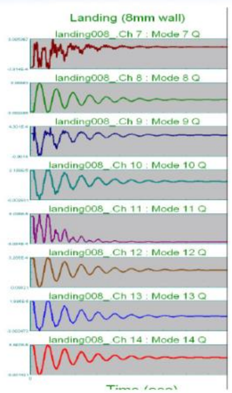
NODYCON 2021
Second International Nonlinear Dynamics Conference
February 16-19, 2021

Multibody: Fatigue Analysis (notes) – 9.2

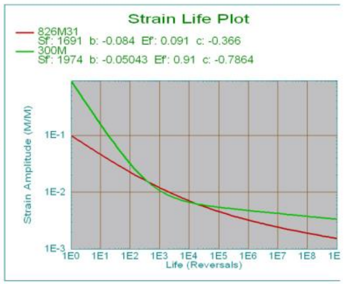


- Loads & Stresses (from MSC.ADAMS)
  - Modal coordinate time histories
  - 42 modes (0-1000Hz)
  - Modal stresses



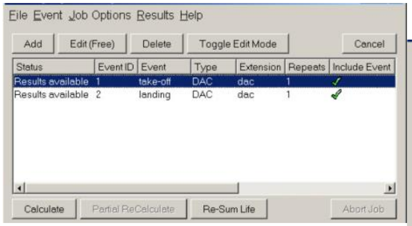


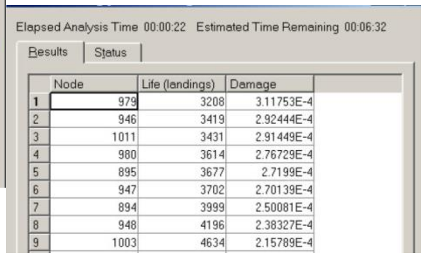
- Quenched & tempered low alloy wrought ste
  - **826M31**
    - σ_y =800MPa
    - UTS=1200MPa
  - **300M**
    - σ_y =1500MPa
    - UTS=1900MPa



Combine multiple MSC.ADAMS analyses

Run as single fatigue analysis

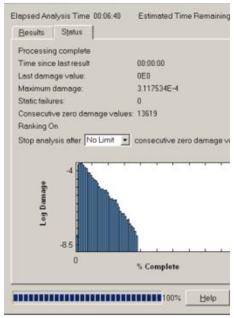




Elapsed Analysis Time 00:00:22 Estimated Time Remaining 00:06:32

Results | Status

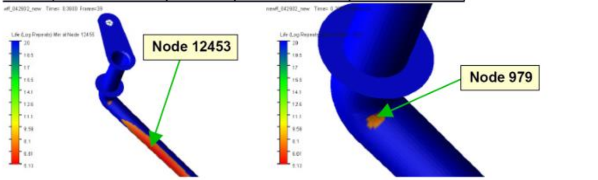
	Node	Life (landings)	Damage
1	979	3208	3.11753E-4
2	946	3419	2.92444E-4
3	1011	3431	2.91449E-4
4	980	3614	2.76729E-4
5	895	3677	2.7199E-4
6	947	3702	2.70139E-4
7	894	3999	2.50081E-4
8	948	4196	2.38327E-4
9	1003	4634	2.15789E-4



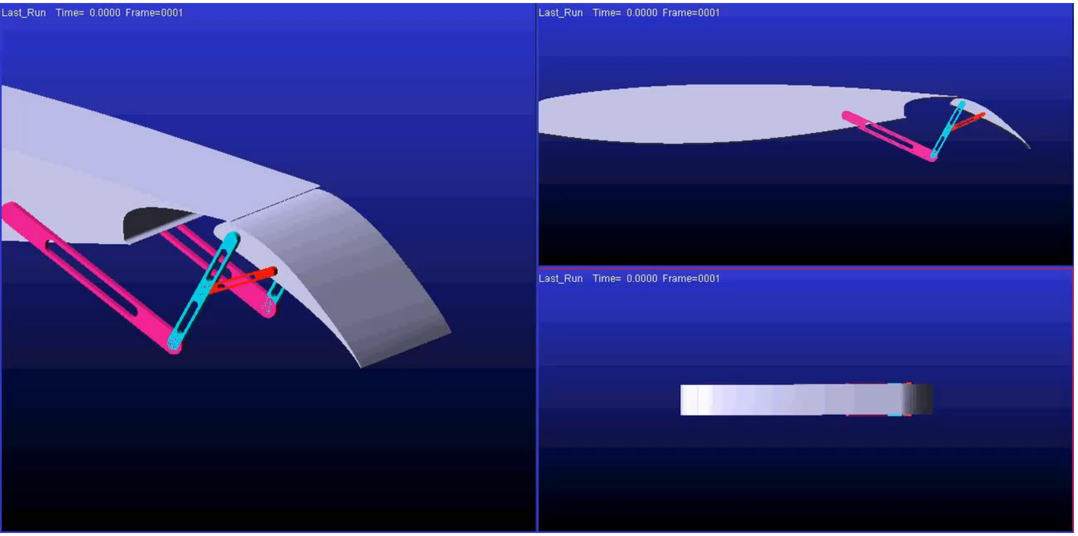
- **Fatigue Results Summary**

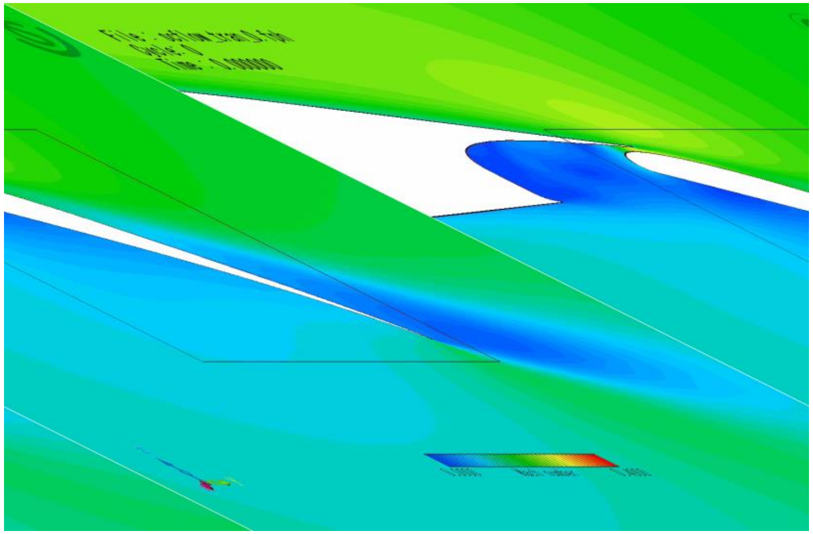
	Wall thickness	Material	Life (missions) Node 979	Life (missions) Node 12453
Case1	8mm	826M31	<1	3148
Case2	8mm	300M	3207	27605
Case3	24mm	826M31	3.269e7	1.234e6
Case4	24mm	300M	>2e8	>2e8

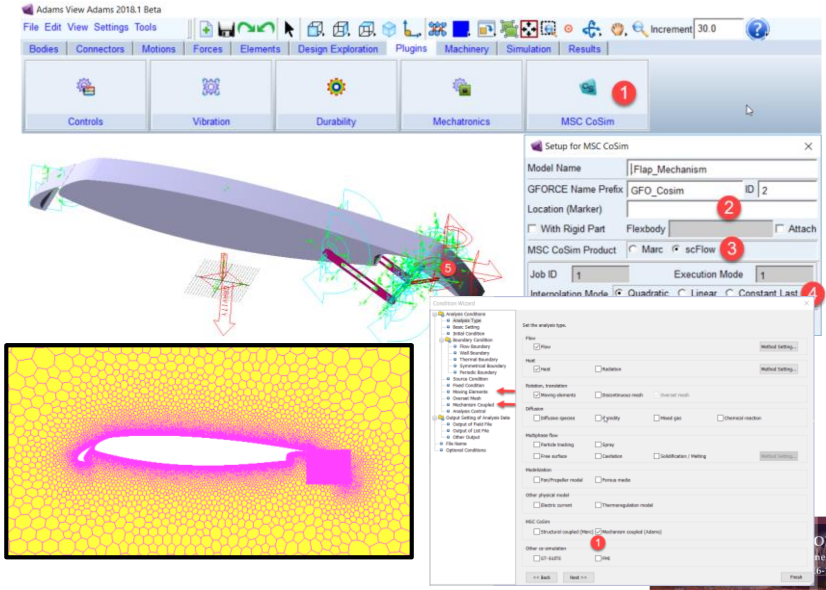
Target Life
12,000 miss

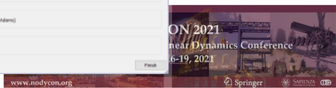


Multibody: Co-simulation MB-CFD – 10

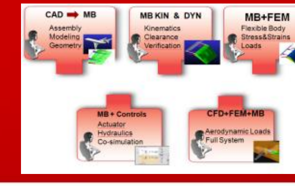






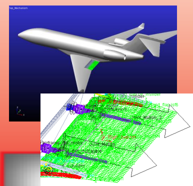


Multidiscipline analysis



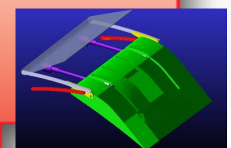
CAD → MB

Assembly
Modeling
Geometry



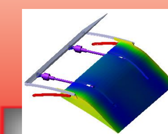
MB KIN & DYN

Adv. Kinematics
Clearance
Verification



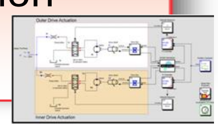
MB+FEM

Flexible Body
Stress&Strains
Loads



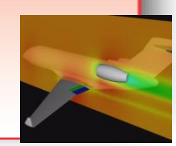
MB + Controls

Actuator
Hydraulics
Co-simulation

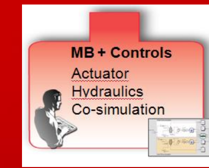


CFD+FEM+MB

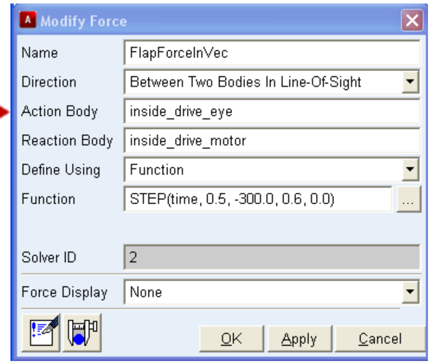
Aerodynamic Loads
Full System



Multibody: Actuator – 12.1

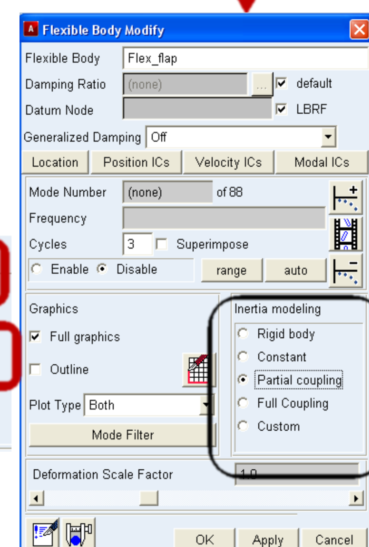


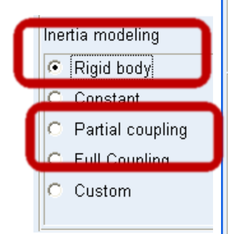
Replacement SFORCE to MOTION



-f(disp)
-f(vel)
- f(time)
-BISTOP to model Stopper

DEACT MOTION





Comparison Rig/Flex Analysis
END =8 s
STEPS = 800

Verification

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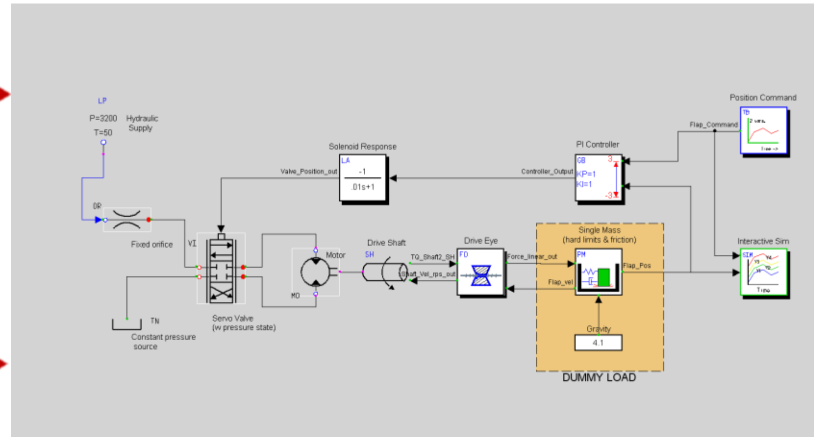
Multibody: Mechatronic – 12.2

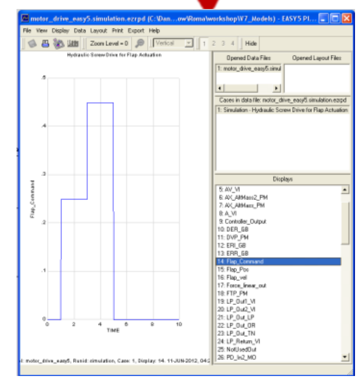
MB + Controls
Actuator
Hydraulics
Co-simulation

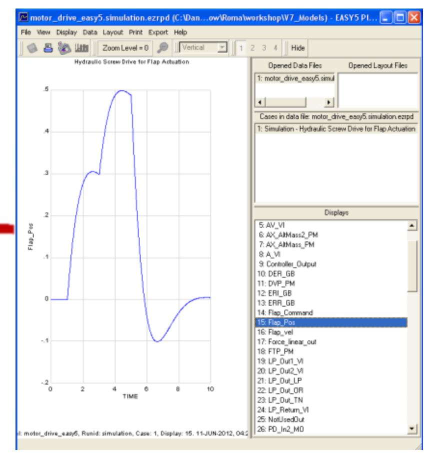
Definition of control system in EASY5

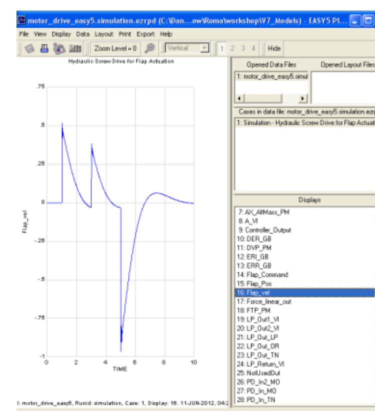
Dummy Multibody model



simulation





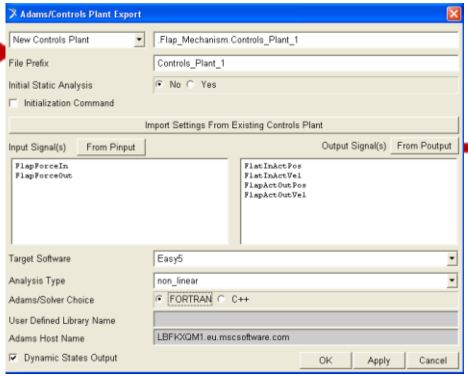


Verification:
Model = flap semplice
No flexibility
No aerod.
No visualization

Multibody: Mechatronic – 12.3

Definition Control Plant:

Input/output signals



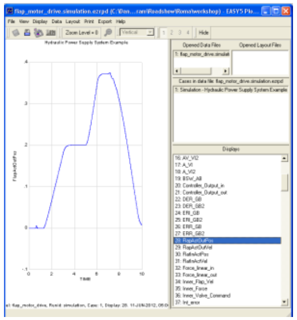
Modelling Control System with Adams Block

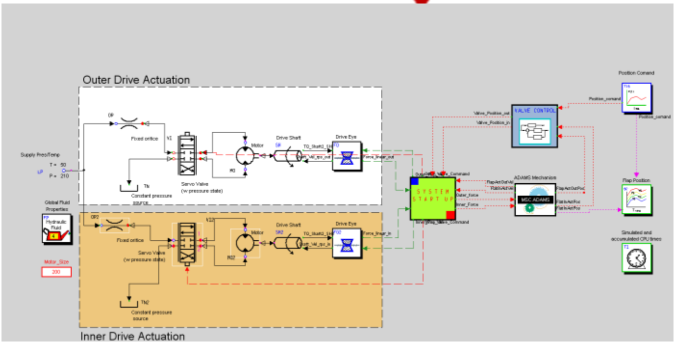
Actuator with Input = State Variable

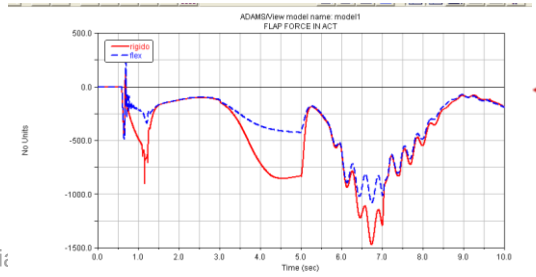
Variable with FU=0 because

Values are assigned from Control System

Output=pos,vel in/out







Verification/ Comparison

Cosimulation RIG / FLEX

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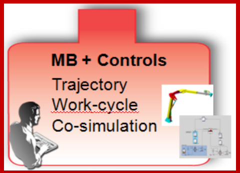
Multibody: Mechatronic – 12.4



DLL export from EASY5

Plant Import and GSE creation in Adams/View

DLL

Analysis with Adams/solver and GSE

Verification

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Thank You!