HELICOPTER SHIP DYNAMIC INTERFACE MODELLING WITH ADAMS

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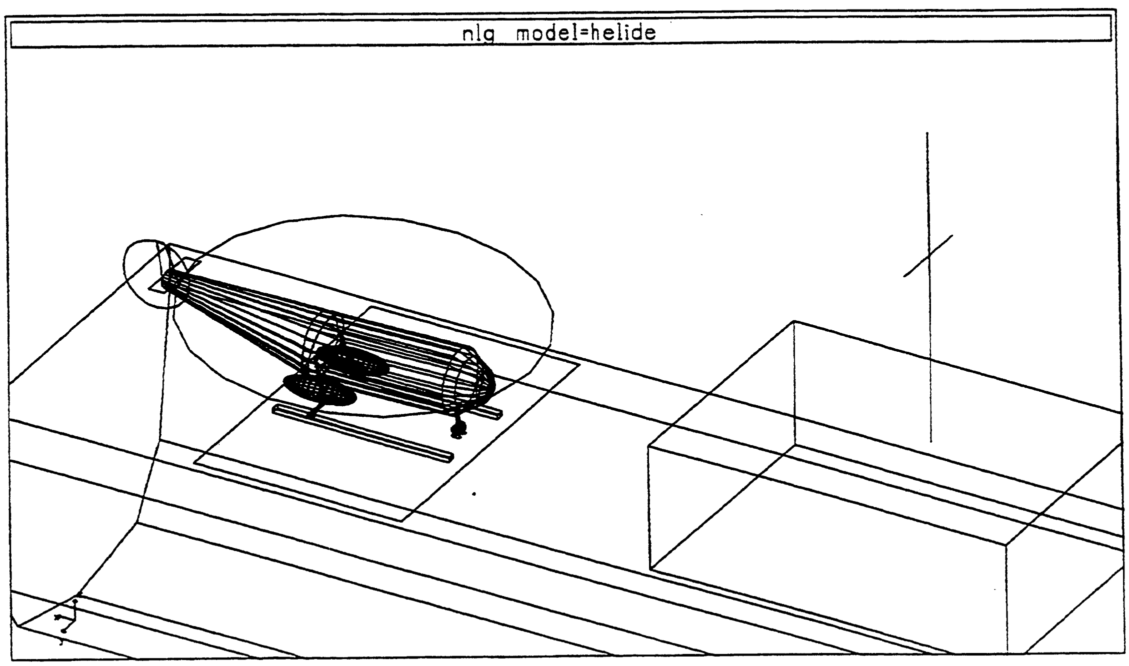
1. SCOPE

The purpose of this document is to describe the main features of the Helicopter Ship Dynamic interface model that has been developed by the Riva Calzoni CCT (Technical Computing Center) using the ADAMS Mechanical Systems Simulation software code.



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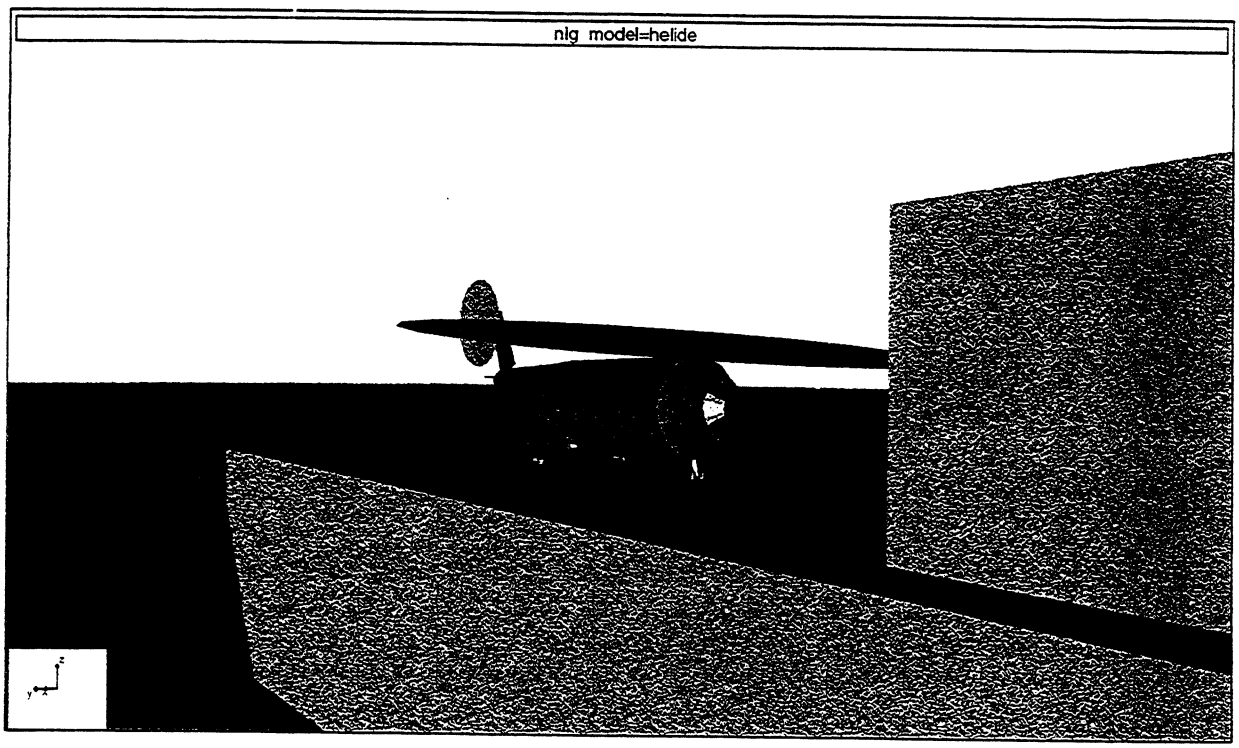
2. INTRODUCTION

The need for accurate prediction of the complex non linear phenomenon of a naval helicopter approaching a moving ship, touching down on it, and being recovered and constrained on the deck or hangar has brought us to develop a numerical model of this system.

We chose to implement it building on the well known ADAMS mechanical system simulation software code, already in use in Riva Calzoni CCT; this choice has freed us from the need to develop fast and efficient algorithms for non linear differential equation solution, in order to focus on the physical representation of the system.

Today the model has reached the stage of a "virtual prototype" that can adequately simulate (if necessary) the touch-down on a moving deck, the subsequent transient during which the motions of the ship quickly become the main exciting influence on the helicopter, and the actions of different securing devices under a variety of dynamic loads.



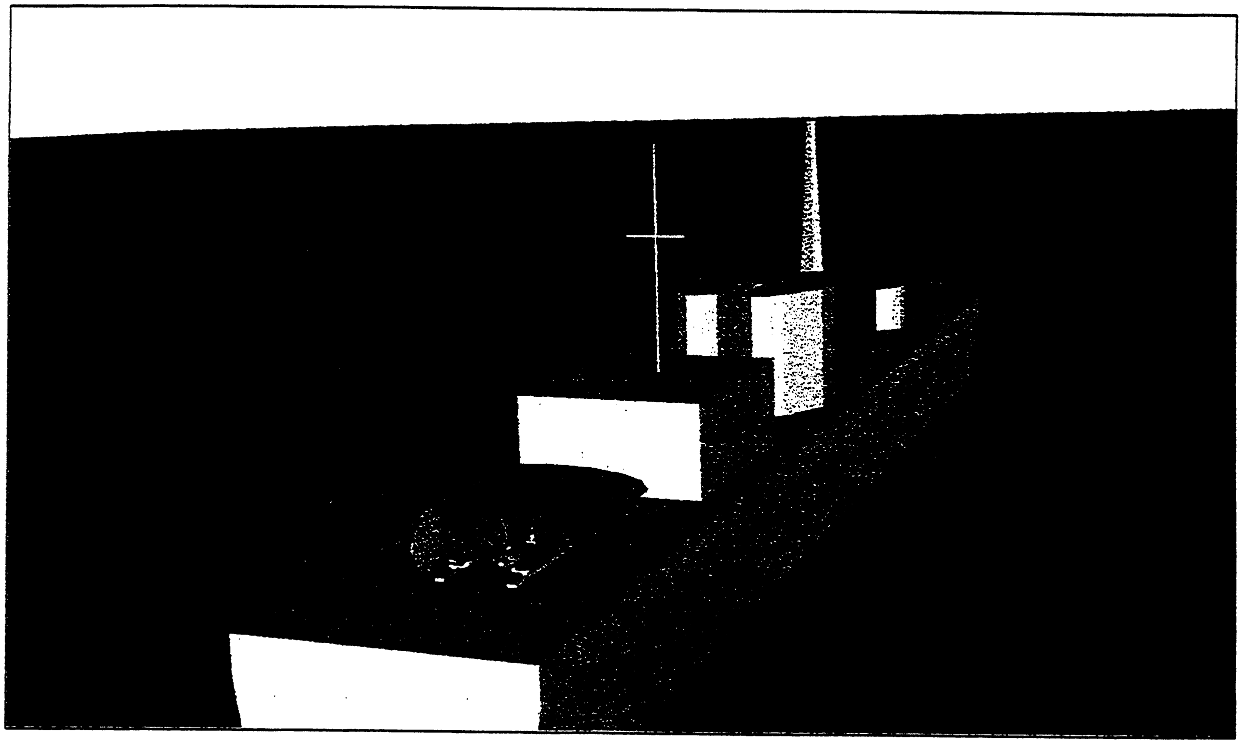
The most technically important features of the model, some of them to be discussed in a little more detail in the next chapters, follow:

- accurate representation of ship motions derived from the sea state, ship speed and heading (Response Amplitude Operators read from Ship Motion Program output, or from generic external files)
- parametrization of almost all numerical quantities

- compact and self documenting modelling architecture, due to the hierarchical source files structure (ADAMS macro + command files features are extensively used)
- complete modelization of all known non-linearities, using numerical or graphical data curves as input (landing gear tires, shock absorbers,...)
- complete tire stiffness and damping model, including impact forces and optionally the lateral stiffness dependency on radial instantaneous load
- sophisticated in-house developed tire friction model, using a generalised smoothed Coulomb law that includes static and kinetic friction
- capability to intercept any "critical event" during the simulation and take appropriate action following it (ADAMS sensor feature)
- different types of securing devices (harpoon, probe, Riva Calzoni RECOVER,...)
- specialised reporting software developed for quasi static solutions (ADAMS file text write feature)

3. SHIP AND SEA MOTIONS

The ship was, at first, the only part of the model that is built and modified interactively with the graphical ADAMS/View pre-processor; now it has been fully parametrized and transformed in a macro file.



In fact the model of the ship answers only to aesthetical requisites, the only parts of it having a numerical influence on the results being:

- the center of mass
- the center of rotation or translation for any of the six Degree Of Freedom (DOF)
- the location of the landing area
- its motions

A complete study and analytical description of how to determine the ship motions knowing the sea state, the ship speed and heading, and the ship Response Amplitude Operator (RAO: generally computed by commercial software like SMP: Ship Motion Program) has been conducted by another Riva Calzoni Department, and has been included in the model architecture.

The output of these calculations are numerical tables describing, as a function of time, the evolution of every one of the six DOF of the ship (heave, surge, sway, roll, pitch and yaw): any one of these is the sum of a certain given number (e.g. 30) of sinusoidal waves with known amplitudes, frequencies and phases.

In order to simplify and automate the translation of the ship motion files produced by the external software into ADAMS "motion" descriptions, a standard format of exchange has been defined. Of the three different choices available for the solution of the problem, namely:

- ADAMS/View CMD language as a stand alone tool (reading the data and rewriting them as a macro file to be used whenever necessary)
- ADAMS/Solver user customisation with a FORTRAN subroutine able to compute the motion and its derivatives
- FORTRAN stand alone program reading the data and writing an ADAMS/View macro file (CMD) to be used subsequently every time needed

the last one has been chosen, for its maximum flexibility: the simple converter software features: free format reading, namelist driven self-documenting input, the ability to suppress individually some of the six DOF motions, and some intervention on the supplied data in order to fit them to the ADAMS/Solver characteristics (scaling factor, time offset, initial smoothing out for a continuos transition from quiet to fully developed sea state, via the haversine function).

An interactive part of the same program, using the same input files can be used to quickly explore the time range of the simulation, in order to find out the extremes of the DOFs variations and focus the simulation on these time interval, if so wished.

As a by-product, it is obviously possible to use this kinematic part of the model to calculate and graph the time history of the displacement, rotation, velocity, angular velocity, and acceleration (and their extremes) of any interesting point fixed to the ship.

In order to provide fast and automated analysis of a lot of different combination of sea states, ship speed and heading, it has been developed an UNIX shell script that iteratively runs the FORTRAN pre-processor, ADAMS/View, ADAMS/Solver, again ADAMS/View for partial post-processing and reporting, for every input file of a given pattern: as a final result the "extreme of extremes" can be found for every variable of interest (DOF, landing grid position, landing grid acceleration, equivalent deck acceleration), together with the sea and ship state and the moment in time when it is reached. A typical run (3 speeds, 12 headings, 2 sea states, 3600 seconds of simulated time) can take 5 hours of DEC 200 Alphastation CPU time.

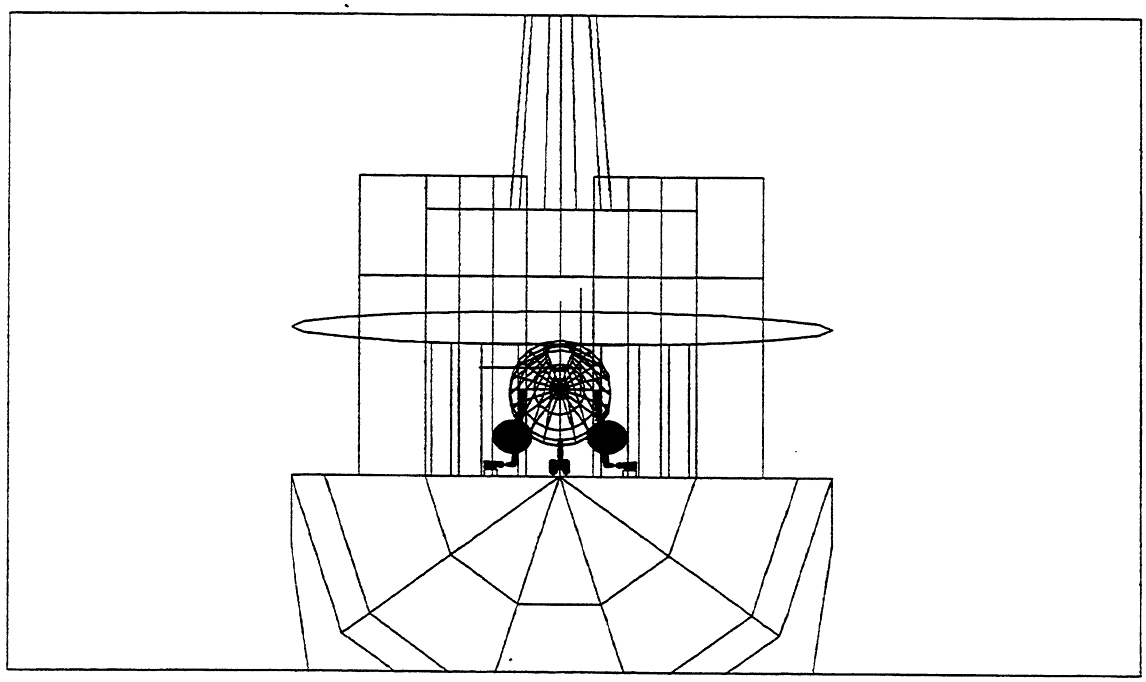
The instants in time so found can then be studied with the helicopter mounted on the ship.

4. HELICOPTER

Body

The helicopter model has been developed interactively in a non-parametric CAD-like fashion, but is now completely described in a stand alone macro file with some 30 ÷ 40 input parameters, whose main categories include:

- Geometrical dimensions (with no influence on the kinematic modelling)
- Kinematic points coordinates
- Mass and inertial properties of the different parts that will be created
- Wind center of pressure data
- Global positioning data of the helicopter with respect to the ship landing area



No attempt has been done to "logically parametrize" the helicopter topology: e.g. the connectivity and geometry of the Main Landing Gear are those of a given type of helicopter (NH90 at present); different helicopter models will have to be created using different macro files, owing to the probably different coordinate systems, number of parts, landing gear geometry and DOFs.

All the helicopter input data are chosen among those directly available from the supplied drawings, so permitting a direct cross-check and an easier maintenance. The helicopter is built in the same coordinate system used by its manufacturer, and the whole assembly of parts and joints is only afterward repositioned with reference to the ship coordinate system (or better to the ship landing area).

The helicopter is obviously not built as a single rigid body (a "part" in ADAMS jargon) but as a certain number of these, connected by "joints" and "forces", sometimes furtherly refined by imposed "motions".

The main body and its connected parts can be defined in the "fully extended" landing gear geometry, or in any "static" attitude derived from external data or from a preceding solution: all the required input data are available from the specialised output reporting described later in this document.

At present there has been no attempt to simulate the moving rotor, with its gyroscopic effect and aerodynamically induced forces: there is only a geometrical representation that has no influence on the simulation results. Of course it is perfectly possible to add it at a later stage, provided that all the pertinent data are known.

NH90 Helicopter

The first (and at present the only) helicopter "model" that has been fully implemented is the Nato Frigate Helicopter 90 (NH90): as an example, it is formed by 4 (four) rigid interconnecting parts (each one with its mass and inertial properties, known or computed):

1. helicopter body (including nose, fuselage, tail, main and tail rotor)
2. nose landing gear vertical leg
3. main landing gear left leg
4. main landing gear right leg

The Nose Landing Gear (NLG) leg is connected to the body by a cylindrical joint (i.e. allowing 1 rotation and 1 translation) and connects to the NLG tires, to be described further on. Also, a force simulating the NLG Shock Absorber (SA) is exchanged between leg and body, and a motion can be imposed on the rotation of the leg about its vertical axis (steering action).

The Main Landing Gear (MLG) legs are hinged on the body with a revolute joint (i.e. allowing only 1 rotation) and bring the MLG tires. Two symmetric forces acting between appropriate points of the body and of the legs represent the MLG SAs.

Tires

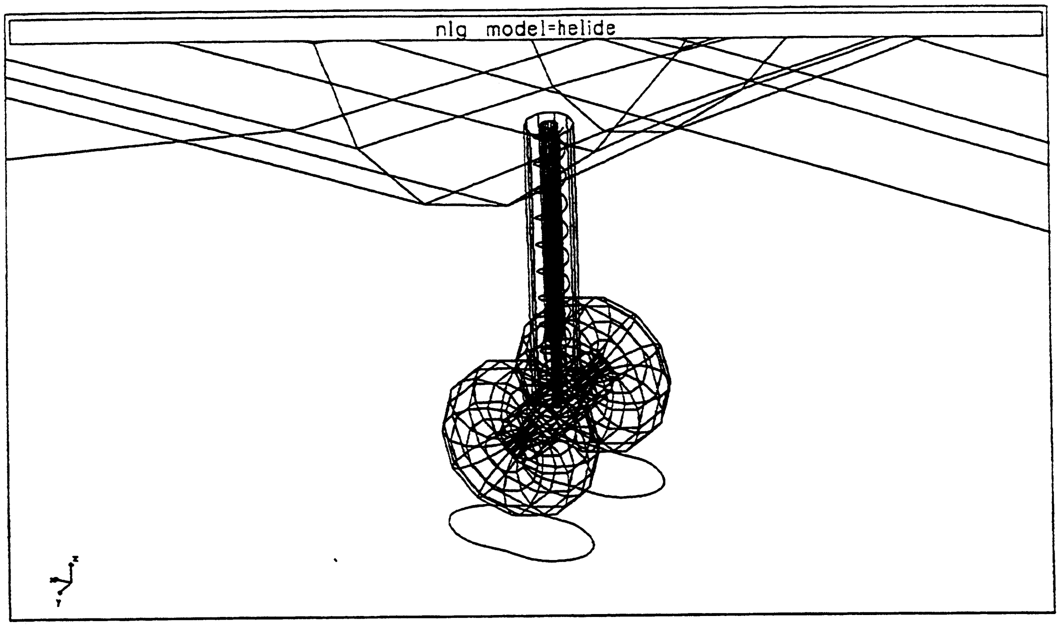
As it can be supposed that the tire elasticity has a very important effect on the simulation result, a remarkable amount of time has been spent trying to develop and test a reliable and complete tire model.

The ADAMS software code has a built-in TIRE statement, using some mathematical models of a revolving tire available from the literature. Some testing and inquiring about this obvious first choice, using purpose built virtual prototypes of tire testing machines, have convinced us to develop our own in-house tire model (RCTIRE).

Reasons for doing so include:

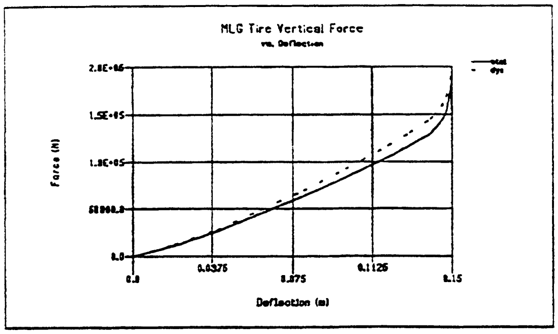
- all the ADAMS models describe well a revolving tire, and dedicate a great effort to the simulation of the road-tire dynamic interaction; some of them simply don't react when their angular velocity is zero; for the same reason the emphasis is not on the non linear stiffness and damping properties of the rubber, that is generally linearized; our problem on the contrary needs this kind of details, and do not need the revolution phenomenon simulation
- the analytical tire models use data that are not available from the helicopter tire manufacturers; by developing our own mathematical model we have been sure to include all the features described by the data available to us
- with no exception, all the ADAMS tire models stand on a steady road: thus showing their orientation to the vehicle simulation problem; of course we could have reduced the ship deck motion to equivalent accelerations, but some reasoning on the implications of this choice made us reject it.

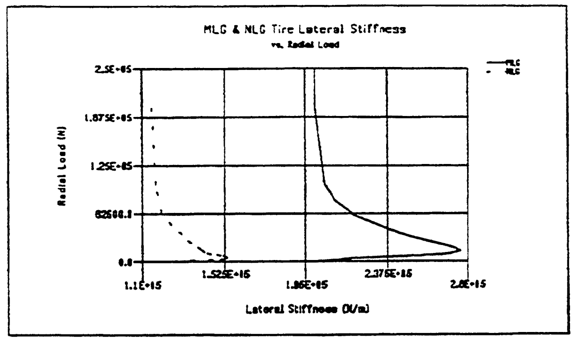
What came out of this is an ADAMS macro file (RCTIRE) that has a general applicability every time it is needed to simulate a mainly static tire, with a non linear stiffness, capable of bouncing on a supporting part, of sliding laterally and of revolving longitudinally (or sliding, if braking), and of inclining its revolution axis with respect to the supporting part.



Every call of the macro creates one tire and its associated parts and geometry; input parameters (with self-updating defaults to minimise repetitive input) are about 40 at the moment. Their categories include:

- Naming and attachment parts: the RCTIRE will exchange forces between two generic parts called the "vehicle part" and the "ground part" (of course not necessarily the ground itself!)
- Location (in the "vehicle" reference system) and initial conditions
- Masses and Inertial properties
- Geometry (i.e. carcass radius, tire radius,...): the tire is drawn as a torus surrounding a central cylinder, but no deformation effect will be shown
- Vertical forces definition: the main non linear load - deflection curve is given pointing to a spline created by reading and external data file (it can be chosen the static or dynamic data), while other parameters are given as single real numbers. The vertical forces include the impact (i.e. they are monolateral) and the rubber damping effect.
- Longitudinal and lateral forces data: these forces are, again, the stiffness and the damping; an input flag optionally permits to create a lateral stiffness as a function of the radial instantaneous load (in this case pointing to another spline created from external data file), or a constant one.
- Friction model definition: the mathematical definition of the friction is a very interesting problem, and its numerical simulation creates many convergence difficulties due to its inherently abrupt change from zero to finite sliding velocity. We have adopted a curve originally suggested by MDI Italy (the ADAMS software Italian vendor), modifying it in order to work in a plane (and not for a translational joint).





The tire model has been tested in stand alone situations, and is perfectly able, for example, to simulate the initial deflection followed by detachment and sliding, and then a new stop if the exciting force is extinct or changes of sign; or it has been shown to simulate the sliding due to a very fast braking; or, last but not least, the multiple bouncing in the vertical direction if the impact speed is sufficiently high.

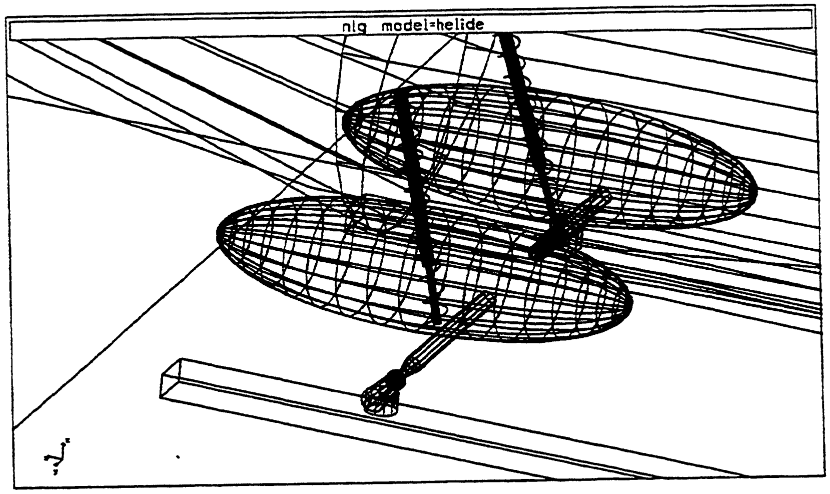
It is very important to remember that the above model is a dynamic one: as it can be easily seen, when the speed is exactly zero, there is no friction force. This fact has the remarkable consequence that it cannot be used for "static" simulations (in the ADAMS meaning of the word, i.e. the solution of algebraic equations): all the so-called static solutions that have been produced are the result of what we call "slow dynamic" simulation, where the rate of change of the applied loads and motions generates negligible forces with respect to the static solutions.

For every tire the macro also automatically generates a set of output requests that integrate the internal variables, permitting, after the run, to graph and evaluate deflections, loads, sliding velocities, and so on.

Beside this, every RCTIRE generated tire contains a comprehensive set of parametric "sensors" (ADAMS jargon for an automatic event identifier, triggered by any user-defined function reaching a predefined value) that during the simulation will continuously monitor the status of this tire: sliding status, inclination, bouncing, excessive deflections, ...; every sensor can optionally stop the run if the user so wishes.

Shock Absorbers

The Shock Absorber (SA) has requested the development of a simpler macro file, that is used for every SA in the model (e.g. three times for the NH90).



It creates an action-reaction force acting between two given points to connect, and an appropriate spring-damper geometry to show its position; no part (and hence no mass) is associated with this element.

The expression for the force contains a stiffness component, that can be derived from a load-deflection non linear curve pointing to a spline read from external data files (as for the tires, the static or dynamic curve can be chosen), or can be analytically defined from the politropic equation of the gas law:

$$F = (p - p_b) \cdot A_0$$
$$p \cdot V^n = const = p_0 \cdot V_0^n$$
$$V = V_0 - A_0 \cdot deflection$$

where V is the gas volume, p its pressure, A the equivalent area of the cylinder, and the index "0" represents the initial condition (in this case the switch from the static to dynamic curve translates into a change in the politropic exponent "n").

The damping term of the complete shock absorber force can only be analytically defined as follows:

$$F_{damping} = C_{1-in} \cdot V_r + C_{2-in} \cdot V_r^2 \qquad \text{when } Vr < 0$$

$$F_{damping} = C_{1-out} \cdot V_r + C_{2-out} \cdot V_r^2 \qquad \text{when } Vr > 0$$

where V_r is the radial relative velocity, positive during the outstroke and negative during the instroke. This simple but non-linear law is however general enough to represent the actual supplied data, and could be arbitrarily complicated, if and when necessary.

If the shock absorber is to be applied and drawn in the "fully extended" position, then its free length can be automatically determined by the macro using the distance between the application points; otherwise the user can supply the free length in the call, in order to permit the assembly of the model in any (previously computed) static position.

Forces and Imposed Motions

The model is subjected to a vertical gravity field, and to some other forces, any one of these being an arbitrary function of time; they include:

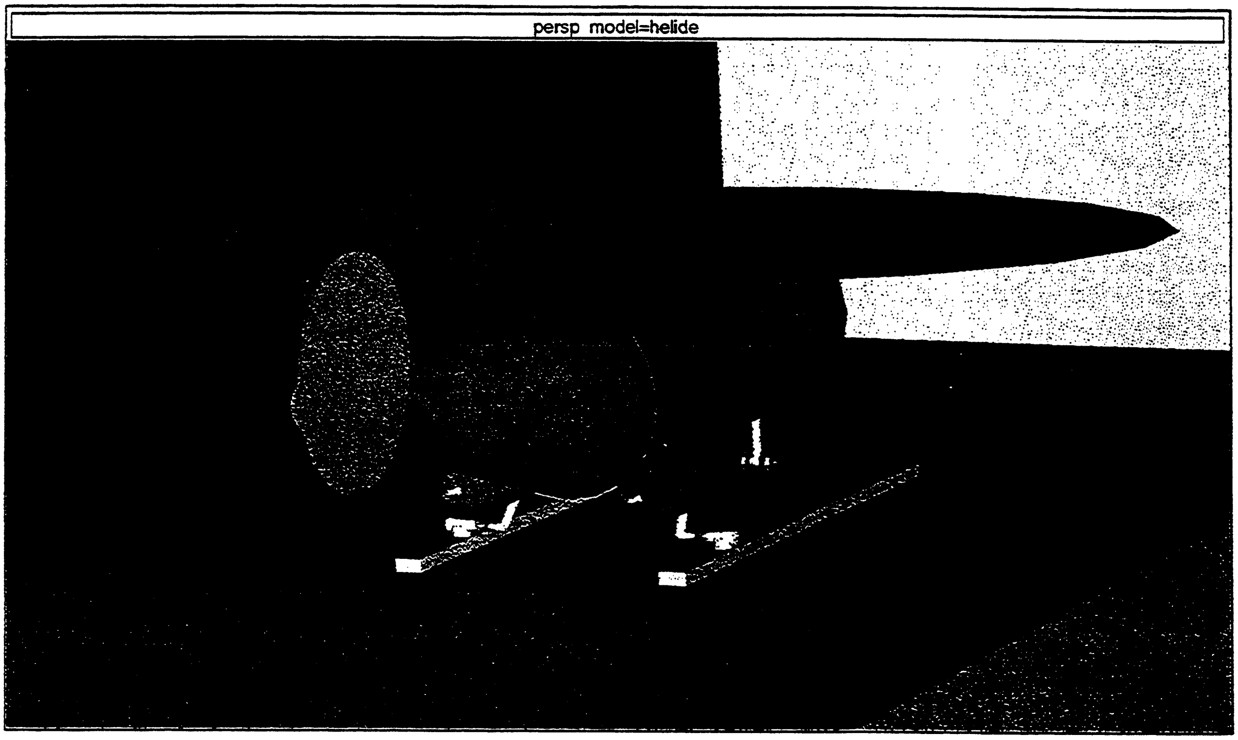
- Inertial forces: applied on the helicopter center of gravity, they are to be used only in quasi static simulations, in order to represent the accelerations due to the ship motions; of course in a dynamic analysis with realistic sea motions, the software will automatically apply the correct time-varying forces, so this component will be zeroed out.
- Wind Forces: applied on two different centers of pressure for the longitudinal and lateral wind: at present there is no computation of equivalent area or wind speed, the requested input is simply the time history of the force expressed in Newton.
- Rotor Thrust: applied to the helicopter center of gravity, it is a very simple mean, with no built-in aerodynamical model, used to realistically represent the touch-down transient, when the rotor thrust smoothly decreases, over a given period of time (e.g. 1 second), from a given fraction of the helicopter weight (e.g. 2/3 of it) to zero.
- Tail Rotor Thrust: also an arbitrary function of time, is applied to the tail center, and can be used to manoeuvre the helicopter on the deck or in the air.
- Deck Lock: a vertical force used to restrain the helicopter to the deck (no harpoon modelling is included: there is no dependency of the force magnitude on the position of the point of application).

Beside this, a set of imposed motions changes dynamically or quasi statically the helicopter loading, due to the orientation with respect to the gravity, and/or to the friction forces direction: they obviously include all the six ship DOFs motions, and, for the NH90 helicopter type, the NLG steering about its vertical axis (to dispose it longitudinally or transversally).

5. CONSTRAINT TYPES

A number of securing devices can be simulated using the wide range of ADAMS software tools: the implemented model architecture in the first stage assembles the helicopter on the ship, and then optionally creates "around it" the wanted constraint type.

Beside the simple standing on the deck resting on all four tires (NH90), eventually tied down by the deck-lock force expressed as a function of time, it has been tested the development of Riva Calzoni RECOVER equipment (BCD: Beams Clamping Device), including its hoisting capability acting on the MLG tire hub.



Concerning Riva Calzoni RECOVER equipment, a special care has been put in the definition of the so called "Load Sharing Device (LSD)", an active part of the system targeted at limiting (via hydraulic actuators) the maximum admissible lateral load on the helicopter MLG leg. Different design solutions have been tested and evaluated: the numerical parameters (intervention forces, actuator forces, time delays, ...) of the final solution will be optimised running simulations of different extremes sea states and choosing the set that minimises the total load on the Main Landing Gear.

Other interesting restraining schemes that have been developed are the harpoon and mooring cables.

6. OUTPUT

Sensors

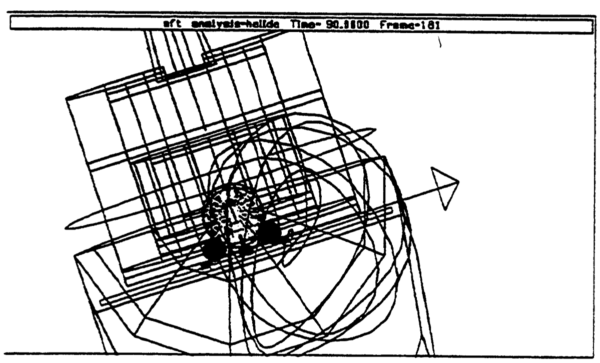
Before running a simulation, the user can choose to activate or deactivate selectively a wide range of "sensors" that are automatically created by the macro files of the model; or can add new ones, in order to test particular aspects of interest in a specific simulation.

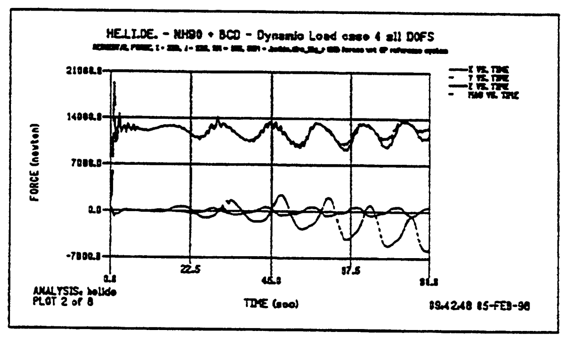
For example, as a standard, there are sensors for each tire that will optionally stop the simulation when each of the three deflections will go over a predetermined parametric level; or when the tire detaches itself from the ground part (in this case only a notification is wished, because the model is perfectly capable of handling the bouncing).

The same is true for the Shock Absorber, whose load - deflection curves are obviously limited between the fully extended and the fully packed position, and whose damping force laws àre valid only for a certain range of relative velocity of deflection.

Output Data

ADAMS software produces for every simulation run such a wide range of results (in the form of displacement, rotations, velocities and acceleration, forces, internal variables values, and so on) that it is a problem in itself the choice of "what to look for" and in which reference system (static or moving...).





The model architecture that has been implemented creates a remarkable number of important "requests" of data output (adding to the standard ones that ADAMS produces regardlessly of user wishes); and again, if the user needs, it is possible to add specific requests concerning a particular simulation.

For example, any tire brings with it a request concerning all the forces and moments exchanged in its hub between the tire itself and the supporting part; any shock absorber creates requests for its force, deflection, and deflection velocity, and so on.

Any system-produced or user-requested data can be automatically charted as a function of time; different charts (load-deflection, vertical force - horizontal force, ...) can be created with a little more interactive work, or can be automated, if the needs arises, of course with macro files.

Reporting

ADAMS software philosophy has been to automate the creation of very good graphics, both in the form of fast interactive on-screen animations, and, as mentioned before, of standard charts of any result in function of time, or of any other result.

But when the helicopter model is used "just" to reach a static equilibrium solution (or better a slow dynamic one), the time history of how it is reached is of no interest, while we need a comprehensive report specialised for the problem under examination. There is no "report generator" in the actual release of the code, but it is amply compensated by a very general capability of writing out text files with any user defined format and content.

Starting from this, it has been developed a macro file that specialise in reporting a set of about 50 numerical input data (for load case checking) and about the same number of output results (some constraint reactions, displacements, and so on), in a generic step of the simulation (typically the last one, "static" or asymptotic equilibrium), and, for some of them, their difference from another "given" reference step (generally the "equilibrium" under the simple weight of the helicopter and no other load). The report is structured in order to contain an "helicopter report" that stays the same whichever securing device is used, and a specialised "securing reactions report" for every different supported device.

This tool has proved its effectiveness in many ways, and a sample of its output, relative to the Riva Calzoni RECOVER equipment and a typical heavy load case, is shown in appendix A.

Beside this, the "helicopter report" has been implemented in order to contain all the numerical data that can be needed in order to "reposition" the model, in the creation phase, in any desired "static" attitude, that is, not only the "fully extended" and "before touch-down" position.

This means that the report now contains all the coordinates of the main points needed for the model assembly in the helicopter coordinate system (useful also for validation purposes); the three Euler angles and the three coordinates of the helicopter system with respect to the ship; and the computed free lengths of the shock absorbers. All of this can (and must) be input to the creation macros in order to "rebuild" the model with the computed attitude of any solution.

Last but not least, during the many simulation runs, we felt the need for some kind of "sensor reporting": in our model, many sensors are employed as a "warning" tool, that does not stop the simulations but simply writes out that a certain event has happened (tire sliding, detachment, and so on). So a simple FORTRAN program has been developed, that reads the ADAMS .ADM file (to get the cross reference Solver "number" vs. View "name") and the ADAMS .MSG file, where the sensors are written only by number: after this a synthetic report is produced, containing the list of activated sensors, their type, and the first and last time of activation. A sample of this output is appended to the report in appendix A.

7. CONCLUSIONS AND FUTURE DEVELOPMENTS

The Riva Calzoni Technical Computing Center helicopter model is just in its developing phase (work started on it about July '95), even if it is already producing valuable data and remarkable insight in the helicopter - ship dynamic interface phenomenon.

We already know some things that have to be done, but surely other needs will evolve over time.

- New helicopter macro files will be created (EH101,...) for different models and landing gear configurations.
- New securing devices will have to be modelled.
- Helicopter landing gear legs finite stiffness will have to be taken into account, using the BEAM statement of the software, or better its interface with the ANSYS Finite Element Analysis code.
- Post-processing software able to compute, for a generic system "request", how many times the value has crossed a reference level (typically a maximum load), and for how long each time, beside some statistical data on the whole numerical result set.

And, last but not least, a critical look at computational performance of the model will be a must, especially when the long dynamic simulations (e.g. 20000 seconds) asked by some customers will begin. When this will happen, automatic analysis of the pertinent result extremes will also be needed, in order to point out the critical loads on the helicopter and/or on the restraining devices.

A. APPENDIX: REPORTING

Sample Report

A sample of the output produced by the automated "reporter":

```
Riva Calzoni RE.CO.VE.R. system - HElicopeter Limitations on DEck

HELIWRIT - HELIcopter Formatted WRITe results. File name: helide.txt
Riva Calzoni C.C.T. - Ing. C.Pedrazzi

Model: helide    Title: HE.LI.DE. - NH90 - Load Case AHH1b0BE
Analysis: helide   Units: MKS
Results File:   Time & date: 00:34:45 23-MAR-96   Number of steps: 30
Request File:   Time & date: 00:34:45 23-MAR-96   Number of steps: 30

Reported  Step Number:   30   Time: 60
Reference Step Number:   10   Time: 10

=== I N P U T ===

Loads & Status Summary (in the GROUND reference system)
======================
Ship Euler Angles : R1=          +0  R2=          +15  R3=          +0
Nlg Euler Angles  : R1=          +0  R2=           +0  R3=          +0
Rotor Thrust  Main: FX=          +0  FY=           +0  FZ=          +0
              Tail: FX=          +0  FY=           +0  FZ=          +0
Deck Lock         : FX=          +0  FY=           +0  FZ=          +0
Inertial Forces   : FX=          +0  FY=       -18200  FZ=      -61971
Longitudinal Wind : FX=          +0  FY=           +0  FZ=          +0
Side Wind         : FX= -6.9428e-12  FY=       -12557  FZ=     -3364.7
Gravity Field     : GX=          +0  GY=           +0  GZ=          +0
Braking           : Nlg_r=  0  Nlg_l=  0    Mlg_r=  1  Mlg_l=  1

Masses & Inertial Properties
============================
Helicopter Mass   : M =       +9100
            Inertia: Ix=     +13826  Iy=       +62673  Iz=      +54215
            C.m.   : Xm=         +7  Ym= +3.6078e-32  Zm=       +2.17
Nose L.G. Leg     : M =       +11.9
Main L.G. Legs    : Mr=       +33.8  Ml=        +33.8
Nose L.G. Tires   : Mr=        +8.2  Ml=         +8.2
Main L.G. Tires   : Mr=       +26.2  Ml=        +26.2

Important Locations & Other Parameters
======================================
Main L.G. Shock Ab: Xs=        +8.8  Ys=        +1.08  Zs=        +2.6
Main L.G. Hub CntR: Xm=      +8.702  Ym=         +1.6  Zm=    +0.75273
Nose L.G. Hub CntR: Xn=      +2.561  Yn=        +0.19  Zn=    +0.54397
Side Wind Cent.Pr.: Xp=      +8.648  Yp= +4.4746e-32  Zp=      +2.339
Longit. Wind C.Pr.: Xp=          +8  Yp= +4.1441e-32  Zp=       +2.07
Tail Rotor Thr.A.P: Xt=     +16.583  Yt=       +0.624  Zt=       +4.32
Deck Lock Attachm.: Xl=     +8.7111  Yl=           +0  Zl=      +1.096

Tire Model Data
===============
```

```
Main L.G. Radius   : Rr=      +0.3147   Rl=      +0.3147
MLG Lateral Stiff.: Sr=     +3.6e+05   Sl=     +3.6e+05
MLG Longit. Stiff.: Sr=       +5e+05   Sl=       +5e+05
Nose L.G. Radius   : Rr=      +0.2235   Rl=      +0.2235
NLG Lateral Stiff.: Sr=    +1.75e+05   Sl=    +1.75e+05
NLG Longit. Stiff.: Sr=     +3.5e+05   Sl=     +3.5e+05

=== O U T P U T ===

Reaction forces (in ship reference system)
===============
                     Longitudinal        Side                   Vertical
MLG tire hub Right: FX=      +2669.1    FY=       +7188.6    FZ=       +15442
             Left : FX=      -2217.5    FY=        +23668    FZ=       +70143
NLG tire hub Right: FX=      +44.317    FY=       +2277.2    FZ=      +4203.1
             Left : FX=      +32.247    FY=       +5522.9    FZ=       +10498

Joint forces (in helicopter reference system)
============
MLG leg      Right: FX=        +4417    FY=        -11174    FZ=       +10713
                  : MX=       -10326    MY=            +0    MZ=      -7452.6
 leg->heli    Left: FX=       +31279    FY=        -12782    FZ=       +35436
                  : MX=      +2937.6    MY=            +0    MZ=       -13613

Shock Absorbers Forces, Deflections & Free Lengths
==================================================
MLG          Right: FM=       +26937    DM=      +0.20887    FL=      +1.9133
             Left : FM= +1.0863e+05    DM=      +0.25515    FL=      +1.9133
NLG               : FM=       +14354    DM=      +0.28212    FL=       +0.844

Displacements (in the ship reference system) from reference step
=============
Helicopter C.m.    : DX=    +0.02001    DY=      -0.14605    DZ=     +0.01642
Main L.G. S.A. Rgt: DX=    +0.03004    DY=      -0.17209    DZ=     +0.04026
 attach point Left: DX=    +0.01868    DY=      -0.17015    DZ=     -0.05048
Nose L.G. Center   : DX=    +0.00083    DY=     -0.057875    DZ=    +0.010419
Helicopter LPRF    : DX=    -0.00258    DY=       -0.0276    DZ=     +0.10072

Reference Displacements (in the ship reference system)
=======================
Helicopter C.m.    : DX=     +1.0457    DY=            +0    DZ=       +1.722
Main L.G. S.A. Rgt: DX=     +2.8546    DY=         +1.08    DZ=      +2.1126
 attach point Left: DX=     +2.8546    DY=         -1.08    DZ=      +2.1126
Nose L.G. Center   : DX=     -3.4277    DY=            +0    DZ=     +0.19321
Helicopter LPRF    : DX=          -6    DY=            +0    DZ=     -0.29473

Absolute Displacements (in the helicopter reference system)
======================
Main L.G.hub Right: DX=     +8.6827    DY=          +1.6    DZ=     +0.70602
              Left: DX=     +8.7119    DY=          -1.6    DZ=     +0.78015
   tire c.p. Right: DX=     +8.6976    DY=       +1.6218    DZ=     +0.41783
              Left: DX=     +8.7149    DY=       -1.5262    DZ=     +0.55086
Nose L.G.hub Right: DX=      +2.561    DY=         +0.19    DZ=     +0.48412
              Left: DX=      +2.561    DY=         -0.19    DZ=     +0.48412
   tire c.p. Right: DX=     +2.5682    DY=      +0.20401    DZ=     +0.27186
              Left: DX=     +2.5676    DY=      -0.15595    DZ=     +0.28698
Leg S/A a.p. Right: DX=     +8.3862    DY=       +1.2907    DZ=     +0.96003
              Left: DX=     +8.3936    DY=       -1.2907    DZ=      +1.0063
Ground line angles: Rr=     +1.3643    Rl=       +2.4579

Tire Deflections (in each tire reference system)
```

```
================
                    Longitudinal      Lateral/Side      Vertical
MLG          Right: DX=  -0.0052633   DY=   -0.021796   DZ=   +0.026174
              Left: DX=  +0.0046842   DY=   -0.073838   DZ=   +0.085438
NLG          Right: DX= -9.2211e-05   DY=   -0.014011   DZ=   +0.011115
              Left: DX= -8.0491e-06   DY=    -0.03405   DZ=   +0.026252

Tire Contact Patch Velocities (in each tire reference system)
=============================
MLG          Right: VX= -0.00019613   VY= -0.00060401
              Left: VX= +3.7748e-05   VY= -0.00040333
NLG          Right: VX= -5.2773e-05   VY= -0.00077154
              Left: VX= -2.0704e-06   VY= -0.00072941

Absolute Rotations (Euler Angles 313 - Z X' Z'')
==================
Helicopter        : R1=     +6.3526   R2=     +17.519   R3=     -6.3616
Helicoptr wrt ship: R1=     +38.306   R2=     +3.0802   R3=     -38.567
MLG leg wrt heli R: R1=     +3.2936   R2=          +0   R3=          +0
              Left: R1=     +1.8995   R2=          +0   R3=          +0

=== H A R P O O N   D E V I C E ===

Important Locations & Other Parameters
======================================
Harpoon Origin    : Xo=     +8.7111   Yo=          +0   Zo=      +1.096
Deck Attach. Cent.: Xc=     +50.733   Yc= -2.1349e-15   Zc=          +9
Harpoon Free Lengt: FL=       +0.57

Reaction forces (in ground reference systems)
===============
                    Longitudinal      Side              Vertical
Harpoon Force comp: FX=     -528.13   FY=      +19374   FZ=      -41539
Magnitude & Length: FM=      +45838   Ln=    +0.61804

Geometrical Results
===================
Angle wrt Helicopt: An=     +7.6863

 === S E N S O R   I N F O R M A T I O N   ===

 ASAVXOMP 01.06 23-MAR-96 01:35:48

 Sensor Name (only if activated)          Halt First Time Last Time  Nact
 ======================================== ==== ========== ========== ====
 tire_Mlg_r_sensor_y_slide                   F    44.12      48.69    298
```