APPLICATION OF EULER CODE TO EVALUATION OF STORE RELEASE IN A HEAVILY DISTURBED AIRCRAFT FLOW-FIELD

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Summary

The prediction of the separation trajectories of the external stores carried on military aircraft is an important task in the aerodynamic design area having the objective to define the operational release envelopes.
To this purpose ALN have developed in the past a standard technique called SSTP (Store Separation Trajectory Program). The comparisons with a lot of flight test results have proved the reliability of this methodology for all kind of stores and release envelopes investigated. Nevertheless in the flow regimes characterized by non-linear phenomena a more accurate approach is needed.
A CFD supported procedure called APRICOTES (Alenia **PR**ocedure for Interference **CO**mputation on Trajectories, Euler Supported) has been developed fixing a new standard in the trajectory calculations.
The new technique is based on the application of 3D Euler code to evaluate and up-date the airloads on the separating store at different steps along its preliminary part of trajectory.
This methodology applied to significant experimental cases has proved its validity evidencing a further improvement with respect to standard SSTP procedure. However the cost of this procedure suggests to treat critical cases of stores released in heavily disturbed aircraft flow field only.

1. Introduction

ALN have developed a standard technique for the store integration (aerodynamic aspects) on aircraft based on a step by step procedure aimed at defining safe release envelopes.
The main tool to reach this target is constituted by the Store Separation Trajectory Program (SSTP), which is used to predict the store separation trajectory and then matched and calibrated on flight test results in a step by step process.
The SSTP program determines the store separation trajectory solving the six degrees of freedom equation of motion utilizing the quaternions technique.
The reliability of the results is function of the accuracy in the determination, for each trajectory step, of the aerodynamic forces acting on the store.
The standard technique determines the airloads on the store utilizing an aerodynamic data set constituted by:

- Clean aircraft flow field defined theoretically through the application of Panel Method or Euler code.
- Sectional free air coefficients of the store. They are defined starting from the global experimental coefficients, derived by wind tunnel test and generally provided directly by the store supplier.
  Splitting them into different contributions (nose, tail, fins, etc.) in proportional way with the equivalent values determined theoretically by Euler code or panel method.
- Captive installed loads representing the initial condition of store airloads when it is in carriage position.

With the present standard technique the airloads on the store are determined splitting the aircraft flow field into two different zones.

"Near Field" where the mutual interference phenomena between aircraft and store have a considerable impact on the store aero-coefficients. Its extension is assumed 2 or 3 times the store diameter below the aircraft.
A correct prediction of the airloads in this condition, due to the complex flow characteristics, generally requires wind tunnel testing of the configuration aircraft plus store in carriage position instrumented with an internal strain gage balance.
These measurements provide the initial airloads conditions to start the computation of the separation, they decay linearly to zero at the end of the near field region and are progressively integrated by the airloads obtained considering the store submerged into the aircraft flow field.

"Far Field" is the region where the mutual interference phenomena are assumed negligible and the airloads are built up superimposing the store on the previously calculated aircraft flow field.

This technique has the advantages to use a fixed aerodynamic data set (A/C flow field, store free-air coefficients and installed loads) applicable to every flight condition to be investigated, so saving cost and time in the computer execution.
The reliability of this methodology has been assessed and verified by a great number of flight test cases covering different types of stores dropped in different separation mode: release of bombs, tanks and containers and firing of missiles from different aircraft.

The present state of the art, based on a fixed A/C flow field could not to be adequate in those speed ranges where strong interference effects take place.
Store geometry coupled with heavy loaded wings (multi-attachment point) often generate intense flow expansions terminating in strong shock waves.
Additionally the proximity of the aircraft air intake to the stores carried under fuselage is responsible of mutual interferences especially at supersonic Mach number. In this case, in fact, the shock system at the intake propagates well below the fuselage and may interact with the released store (fig. 1).
For these reasons the "near field" extension should be wider and the linear variation of the installed loads no more applicable.

Therefore, to handle such complex fluid dynamic phenomena, a new technique able to evaluate the airloads at different steps, along the store trajectory has been developed in ALENIA utilizing the ALN 3D Euler code. This new procedure called APRICOTES (Alenia PRocedure for Interference COmputation on Trajectories, Euler Supported), ref.[1], is articulated in the following steps:

a) Accurate computation of transonic/supersonic flow field via Euler solver.

b) Partitioning of the aero-coefficients on the store.

c) Initial condition at $T = T_0$ (store installed loads, aircraft flight parameters).

d) Immersion of the store in the flow field and build-up of the airloads in conjunction with the installed loads.

e) Trajectory calculation stopped at $T_1 = T_0 + \Delta t$

f) Grid generation of the aircraft plus missile geometry at T_1 instant.

g) Euler code computation of static store aero-coefficient at T_1 instant.

h) Adjustment of static coefficient to take into account dynamic effects.

i) Updating of flow field

j) Restart of trajectory computation with updated aero-coefficients and flow field up to new instant $T_2 = T_1 + \Delta t$

k) Loop from step "f" to step "j" up to the instant where mutual interference phenomena are drastically reduced.

l) Trajectory computation proceeds as for standard technique until the store fully clears the aircraft.

Note: The time interval Δt is chosen on the basis of the store standard trajectory behaviour coupled with the basic aircraft flow field in order to capture the relative positions of maximum interference.

2. The ALN approach to the implementation of CFD code into the aero-design process

In the development of the whole procedure, big emphasis has to be done to the "path" that, starting from an initial geometry, leads to the analysis of CFD results. With the aim to get a quick and reliable process of aerodesign, ALN have adjusted this sequence of operations; an example of the steps of the process is presented in the following:

Ia)* Definition of a "conceptual" model (for instance as first step of a development of configuration) or

Ib)* Utilization of a model from the master geometry data base (yet assessed geometry).

*Ia/Ib in alternative

II) Building up in CAD-CATIA contest of a derived geometry model (by "translating" a series of points in polynomial entities) congruent to that defined in step I. This step allows to reduce the amount of geometrical information to be managed and to verify the possible deviations of the derived geometry with respect to the original one.

III) Possible simplification of the geometry depending on the aircraft area to be analyzed.

IV) Transfer of the geometrical data (polynomial coefficients) from CATIA to the input files of CFD codes with the appropriate format.

The following steps regard the utilization of the Euler Code. ALN have developed a solver code for Euler equations called UES3D, ref. [2]. The aim of this code is to find the flow field stationary solution of a three dimensional compressible inviscid fluid by using a pseudo-unstationary method in time and a spatial finite volume method on unstructured tethraedical meshes, ref. [3], generated by SUR 3D code (surface grid) and M3D code (3D grid).

Using now EULER Code

V) Generation of surfaces (SUR 3D Code) and 3D grids (M3D Code) to have mathematical model ready for the theoretical analysis code.

VI) Theoretical results from Euler equations solutions (UES 3D Code) and analysis of these results.

VII) Optimization of the model on the basis of the result analysis and consequent verification with the theoretical code.

$VIII$) Final assessment and loading of a new model in the master geometry data.

The implemented methodology, having access to a direct way to the mathematical models of the assessed geometries, permits to carry out aero-analysis with strongly representative models.

The application of this methodology allows to quickly and correctly optimize the geometrical model utilized for the aero-analysis.

The optimized geometry can be easily re-inputed in the master geometry data base.

The above described methodology represents the standard procedure of the whole aero-design process. It can be usefully used even in the trajectory calculation limiting the application of the procedure to an aero-analysis contest.

Fig. 2 shows a summary of the methodology for the Euler theoretical code.

3. Validation of the Euler method

The validity of the Euler code UES3D has been assessed comparing the computed results with experimental ones derived by wind tunnel test on contemporary aircraft and missile geometries.
The missile aero-coefficients were measured both for the free-air conditions and for those measured on the aircraft at the end of the guided phase during the missile launch (EOS).

- Free-Air coefficients

The comparison relevant the free-air coefficients for one Mach number case evidenced a good agreement both for the normal force C_N and pitching moment C_m

On the basis of this result the experimental data have been spread into four parts in accordance with the contribution determined by UES3D code for each block of the split missile.

- EOS coefficients

The missile at EOS position represents a condition of high mutual aerodynamic interference between store and parent aircraft, whose theoretical prediction is an hard challenge.

Fig. 3 shows:
- a) missile geometry scheme including balance support,
- b) theoretical prediction (iso Mach contours $\alpha = 0 deg.$),
- c) comparison between theoretical airloads (from pressures integration) and experimental ones on missile. This comparison evidences a good agreement both on longitudinal (CN, CM) and lateral (CY) coefficients.

The good quality of the comparisons confirms the reliability of the UES3D code used to predict the missile airloads even when it is applied to a severe condition as it is the case considering the store submerged into a highly perturbed flow field.

4. Selection of a representative case

The new procedure has been applied to a representative operational case on a modern defence aircraft.

To this purpose the drop-launch of an under fuselage semisubmerged missile at supersonic speed, with long exposition to non linear interference effects and with the store trajectory crossing the shock system generated by the compression waves at the aircraft intake, has been chosen as a significant case.

The time intervals used as a step in the computing loop for the determination of the missile separation trajectory have been determined superimposing the trajectory obtained utilizing the standard method SSTP to the aircraft flow-field in order to identify the hypothetical store positions where the maximum interference between the A/C shock wave system and the store occurs.

Fig. 4 shows the 4 positions A, B, C and D chosen for this exercise.

5. Analysis of the computed airloads and of the mutual interference

A series of airloads comparisons have been organized in order to analyse the mutual interference effects on missile coefficients along its separation trajectory and to evaluate the differences relevant to the adoption of the new procedure with respect to the standard one.

During the separation trajectory the store relative speed with respect to the aircraft produces an induced dynamic incidence affecting the aero-coefficients which is neglected in the application of 3D Euler code.

The load increments, due to these induced angles generated by the separation relative velocities, have been derived from the missile free-air characteristics and added to the static air loads previously determined by Euler code.

The comparison of aero-coefficients regards three split blocks beside the global (fig. 5). As before mentioned, SSTP builds up the airloads super imposing the missile in a flow-field not distorted by the presence of the missile itself. In other terms, local flow utilized in the two methodologies presents different characteristics.

Calculation of the aero-coefficients in the two ways supplies different values as much as the mutual interference between A/C and missile affects the surrounding flow-field.

The comparisons of the airloads derived through the new procedure (APRICOTES) with those in free-air plus dynamic effects presented in fig. 6 give an idea of aircraft/missile interference; while the comparison with those derived from SSTP program give an idea of the differences in the results due to the application of the two methodologies.

As a general statement, the two methodologies show a similar trend in capturing the aerodynamic phenomena as confirmed by the same oscillation mode along missile trajectory. Nevertheless, as expected, in the region close to the aircraft they present different amplitudes due to the mutual interference between aircraft and missile that is taken into account by the new methodology only.

6. Interactive missile trajectory calculation

After the analysis of the aerodynamic effects on a missile moving into the aircraft flow-field; in this part of the paper the differences on separation trajectory produced by the mutual interference phenomena will be investigated.

The fig. 7 shows the strong influence of the aircraft flow field during the missile release. When missile is in position A, its nose is interested by an expansion wave departing from the intake lower lip; when it is in pos. B a shock wave departing from the intake region interests the forebody and the expansion wave interests the afterbody.

Pos. C presents a residual effect of the shock wave on the afterbody.

The trajectory portions obtained for each step utilizing the new procedures (APRICOTES) are merged in a final trajectory and compared with the reference one obtained with the standard SSTP methodology.

Fig. 8 shows the interactive loop utilized to generate the new missile separation trajectory. The missile airloads relevant to the position "A" of the reference trajectory at instant $t = 0.1$ sec. have been determined by UES3D Euler code and they have been utilized as initial condition to compute the second portion of trajectory starting from pos. "A" with linear and angular store velocity components referred to the time $t = 0.1$ sec..

On the new trajectory a second instant at $t = 0.2$ sec. (pos "B") has been identified as condition to stop the computation and updating the missile airloads as it was done previously.

This procedure has been repeated up to pos. "D", in such a way 4 missile trajectory portions have been obtained and built up in a final trajectory.

Fig. 9 shows the comparison, for each motion component, between the reference trajectory obtained with the standard procedure (SSTP method) and with the new one. The biggest differences are evidenced by the pitch angle with higher oscillation values of the new trajectory with respect the standard one. This behaviour can be explained taking into account the differences in the C_m coefficients utilized in the computation by the two methodologies and could be cause of the criticality in case of store with low longitudinal stability values.

The differences between the two methods have been synthesized (fig. 10) in terms of tolerances on vertical and lateral missile displacements which will be taken into account, together with all the other tolerances, to judge the safety of missile separation. Everywhere the clearances will appear critical or marginal the new methodology will be applied.

7. Comparison with experimental results

With the aim to validate this new methodology an application on a significant case, for which experimental results were available, has been carried out.
The release at high speed (M = 0.83) of a bomb having a variable geometry during its initial separation phase has been chosen.
On the experimental trajectory derived by the onboard camera film analysis (fig. 11) four instants have been fixed in correspondence of the most significant events of the bomb separation.

- Pos. A: t = 0.06 sec. beginning of the rear fin opening.
- Pos. B: t = 0.1 sec. completion of the first step of the rear fin opening.
- Pos. C: t = 0.15 sec. maximum pitch down rotation of the bomb.
- Pos. D: t = 0.25 sec. intermediate point in the last portion of the analysed trajectory.

Starting from the A/C master geometry (fig. 12) a simplified geometry (fig. 13) has been derived, through CAD-CATIA support, eliminating those parts considered uninfluent for the evaluation of the flow characteristics around the region taken into consideration.
This simplified A/C geometry coupled with that very detailed of the bomb has been elaborated utilizing the SUR3D code generating the surface grid formed by triangular facets (fig. 14).
Fig. 15 shows details of the 3D meshes submitted to Euler solver for B and D bomb positions.
The comparison between the theoretical trajectory determined through the interactive loop as described at para 7 and the experimental one is shown in fig 16 evidencing a very good agreement both for the vertical displacement and for the pitch angle.

8. Conclusion

Heavily disturbed aircraft flow fields are characterized by a strong interference between the store and the parent aircraft; typical phenomena insisting in this flow pattern are non-linear. This kind of phenomena can not be treated by SSTP standard procedure because this does not carefully take into account the mutual interaction store/aircraft specially in the "near field" when shock system and strong expansion wave occur.

The need for a more accurate prediction of store separation trajectory has been highlighted.

A new procedure has been set up in ALN:
APRICOTES provides full modelling of the mutual interference effects and allows prediction of critical trajectories.

Technicalities have been developed in order to extend the use of APRICOTES to operational level.
In this contest the CAD system has proved its effectiveness:
interfacing of complex mathematical models with grid generation routines and post-processing of the computed trajectories is now easily accomplished.

The comparison between the theoretical and experimental trajectory has evidenced a good agreement allowing to validate the new methodology.

The overall time to generate APRICOTES trajectories is still considerable:

- Reference trajectory (SSTP)
- Euler computation
- Grid generation 4 iterations (up to $t \approx 0.5$ sec). (at least 4 times)
- APRICOTES trajectory
- Analysis

A mode of operation has been identified:

- APRICOTES must be limited to very critical cases
- With this aim in mind APRICOTES must be used to define sets of "dedicated tolerances" to apply to the standard store separation trajectory program (SSTP).
- "Tolerant trajectories" (SSTP generated) must be analyzed searching for critical cases.
- only "critical cases" must be recomputed by APRICOTES

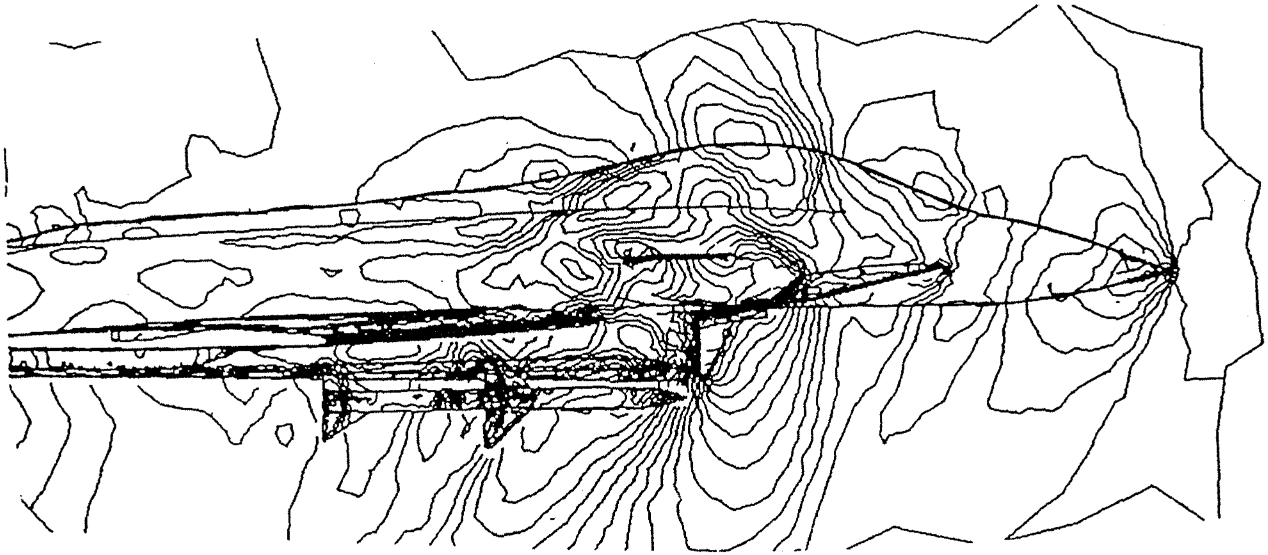
9. References

[1] BARBERO S. I.A. COSENZA, A. SALVATORE; P. VARALDA; "Nuova procedura per il calcolo delle traiettorie di separazione (Euler supported)". ALN Doc. n° 65/RT/T822/920254 Date 09/04/93

[2] SELMIN V.; HETTENA E.; FORMAGGIA L.: "An Unstructered Node Centered Scheme for the Simulation of 3-D Inviscid Flows" In Proceeding of the First European Computational Fluid Dynamic Conference (1992).

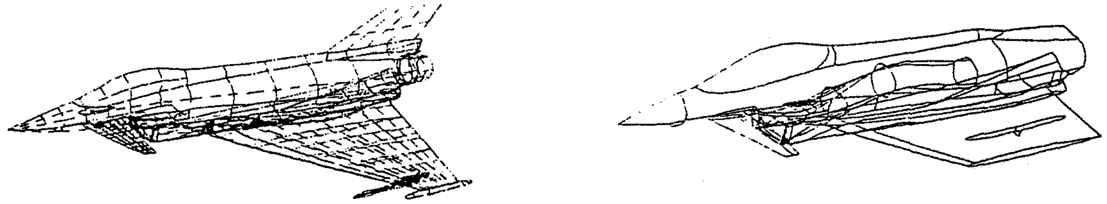
[3] FORMAGGIA L.: "An Unstructered Mesh Generation Algorithm for Three Dimensional Aeronautical Configurations" in Numerical Grid Generation in Computational Fluid Dynamics and Related Fields, A. S. Arcilla et Al. Eds., Elsevier Science Publishers B. V. (North-Holland) pp. 249-260 (1991).

FIG. 1
"NEAR FLOW-FIELD" PATTERN



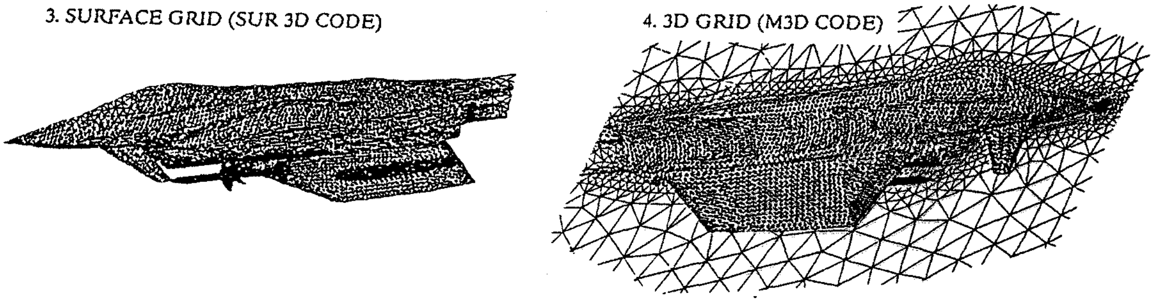
(ISOMACH CONTOURS)

FIG. 2
CFD CODE IN AERO-DESIGN PROCESS: ALN APPROACH



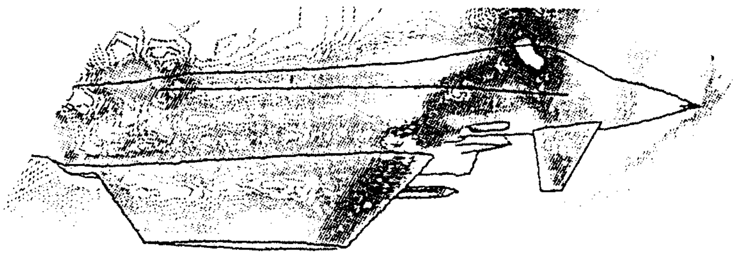
1. ORIGINAL GEOMETRY (CATIA SYSTEM)

2. SIMPLIFIED GEOMETRY (CATIA CONTEST)



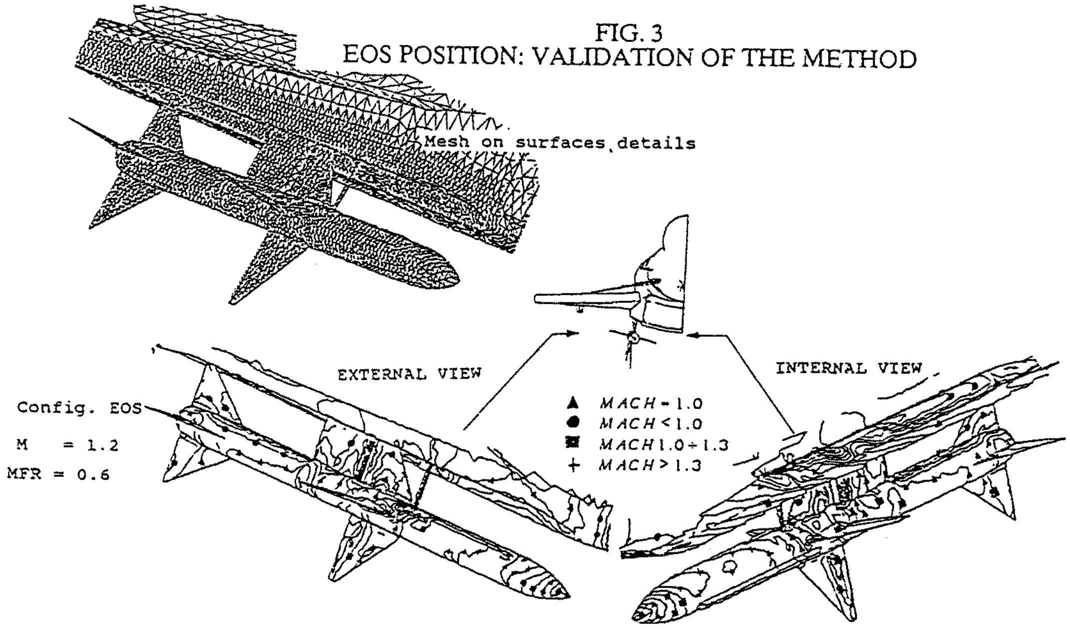
3. SURFACE GRID (SUR 3D CODE)

4. 3D GRID (M3D CODE)



5. THEORETICAL RESULTS EULER EQUATIONS (UES3D CODE)

FIG. 3
EOS POSITION: VALIDATION OF THE METHOD



- Experimental/Theoretical comparison on store loads for missile at EOS position.

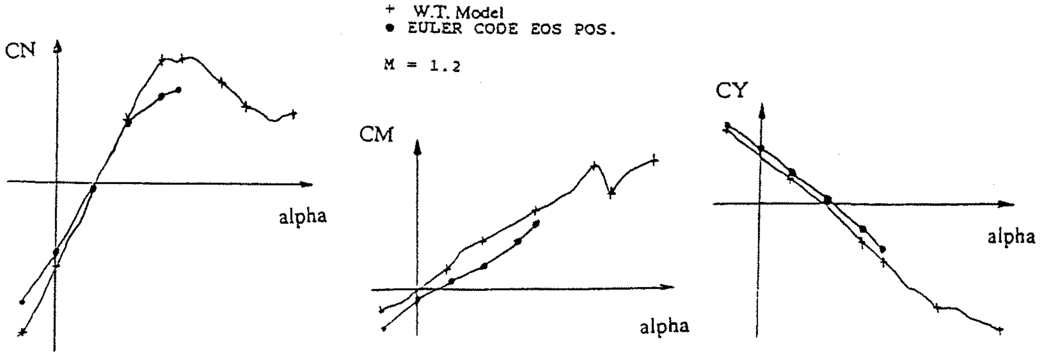
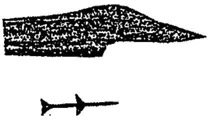
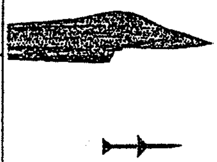
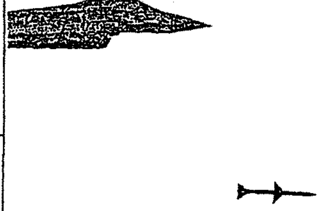


FIG. 4
SELECTED POSITIONS ALONG TRAJECTORY A, B, C, D

CONFIG.		POINTS	ELEMENTS	BOUNDARY	
POS A T=0.10 sec	SURFACES	17104	—	34318	
	3D MESH	110531	598059	34318	
POS B T=0.20 sec	SURFACES	17175	—	34342	
	3D MESH	113481	615011	34342	

CONFIG.		POINTS	ELEMENTS	BOUNDARY	
POS C T=0.30 sec	SURFACES	17162	—	34316	
	3D MESH	113923	617544	34316	
POS D T=0.45 sec	SURFACES	17180	—	34352	
	3D MESH	113982	665204	34352	

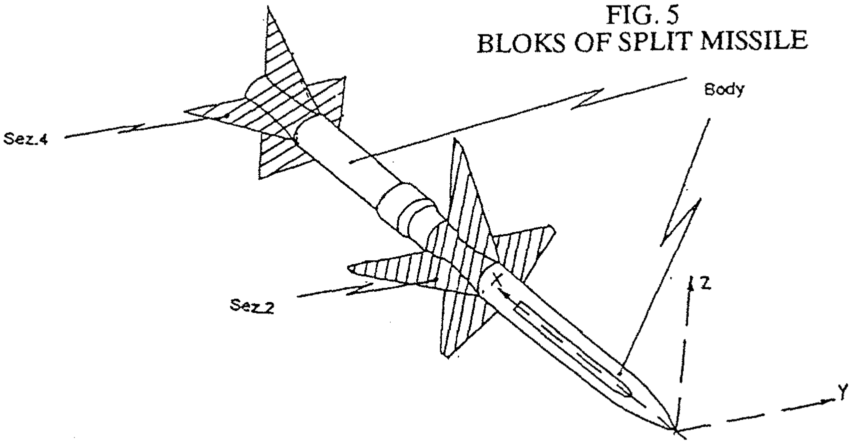


FIG. 5
BLOKS OF SPLIT MISSILE

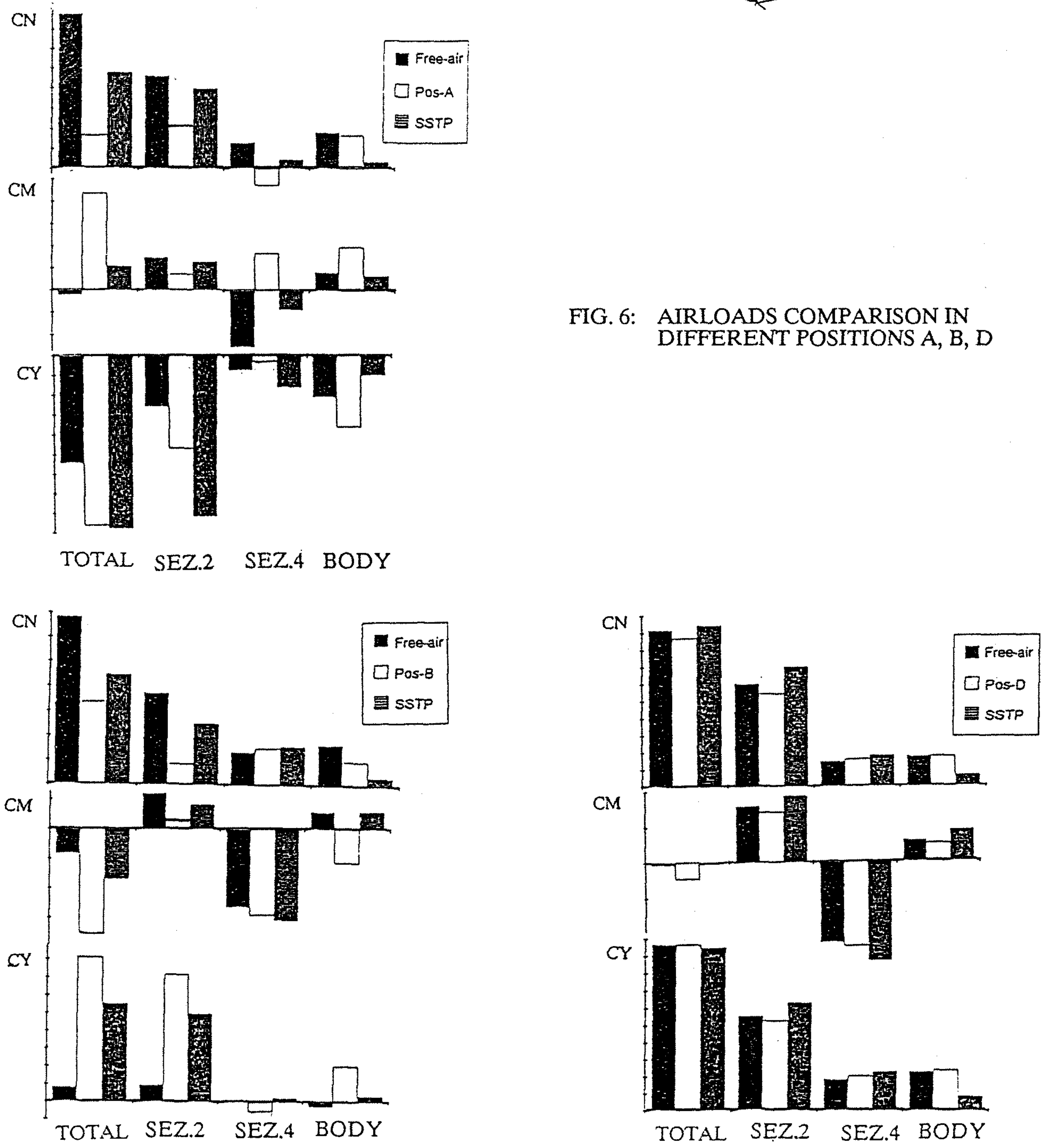


FIG. 6: AIRLOADS COMPARISON IN DIFFERENT POSITIONS A, B, D

FIG. 7
FLOW-FIELD IN DIFFERENT MISSILE POSITIONS
(ISOMACH CONTOURS)

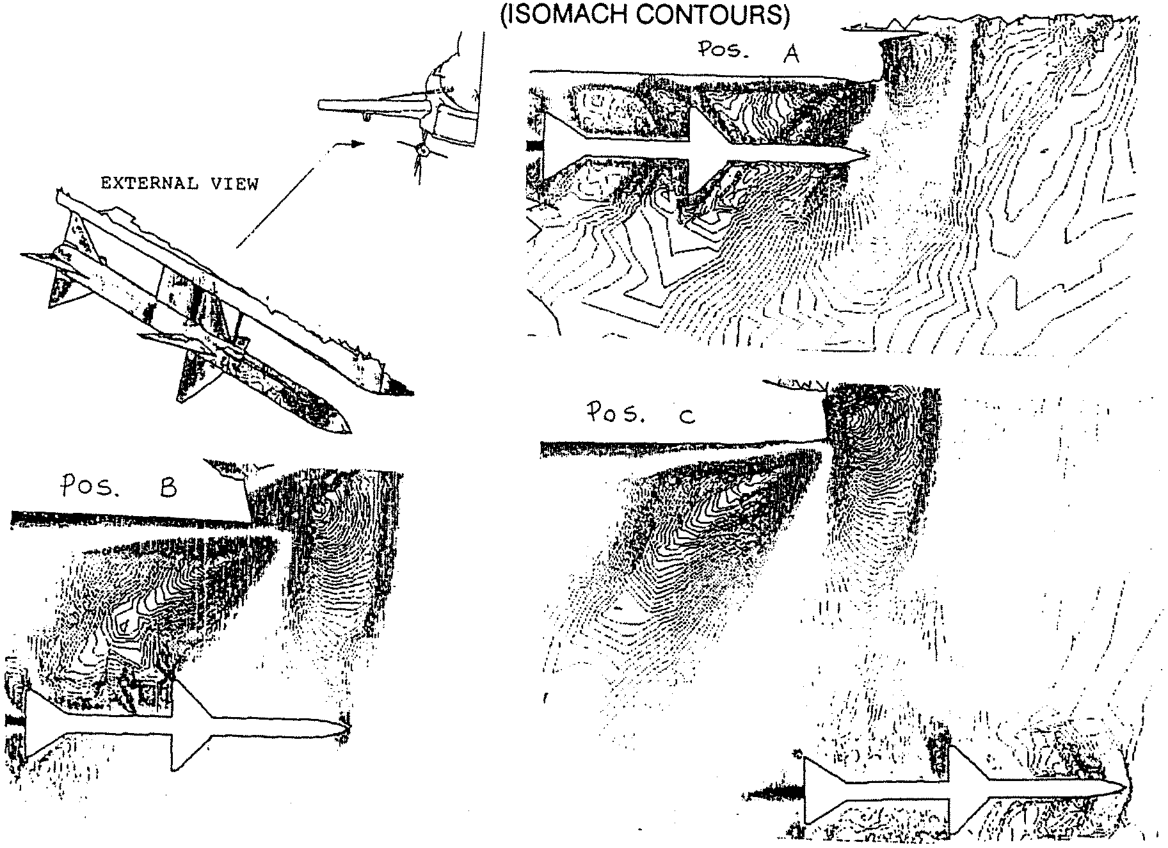


FIG.8
INTERACTIVE LOOP TO GENERATE NEW MISSILE POSISTION

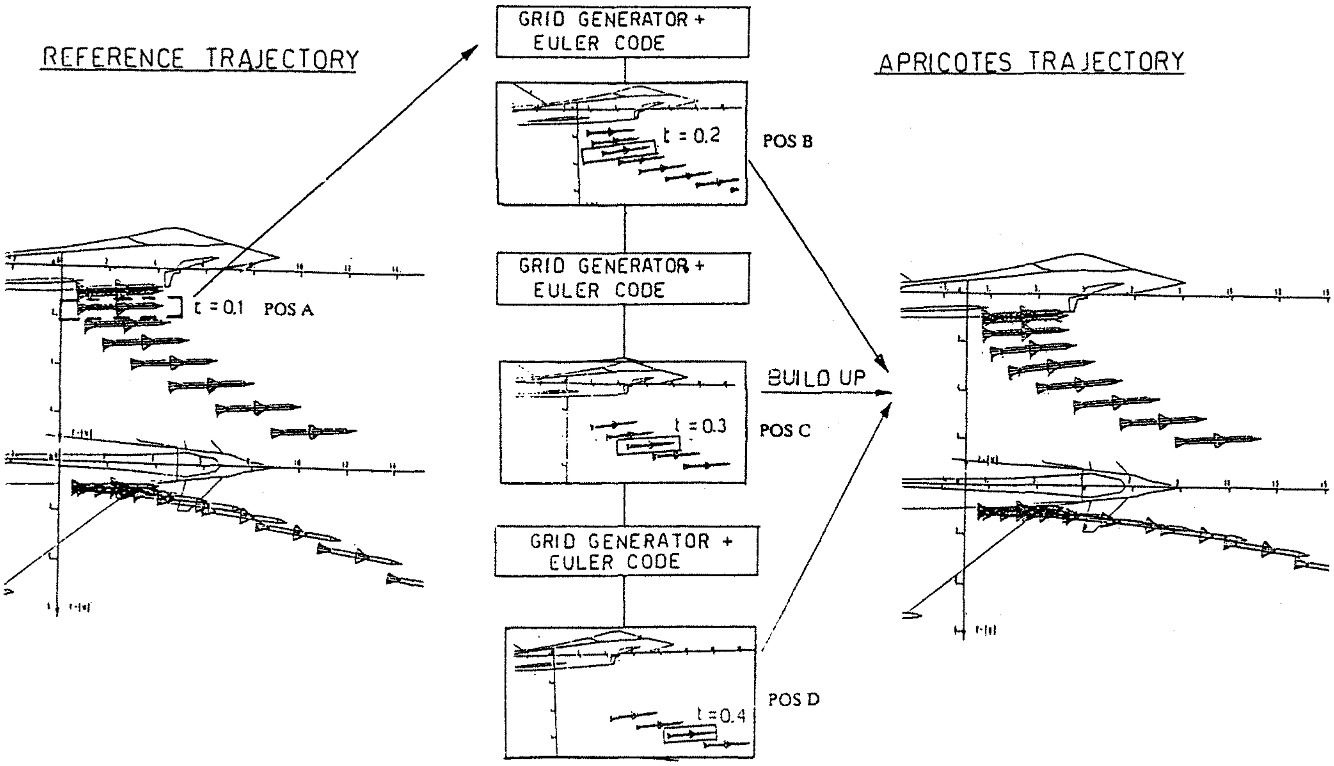


FIG. 9

SSTP (Standard Procedure) Vs APRICOTES (New Procedure)

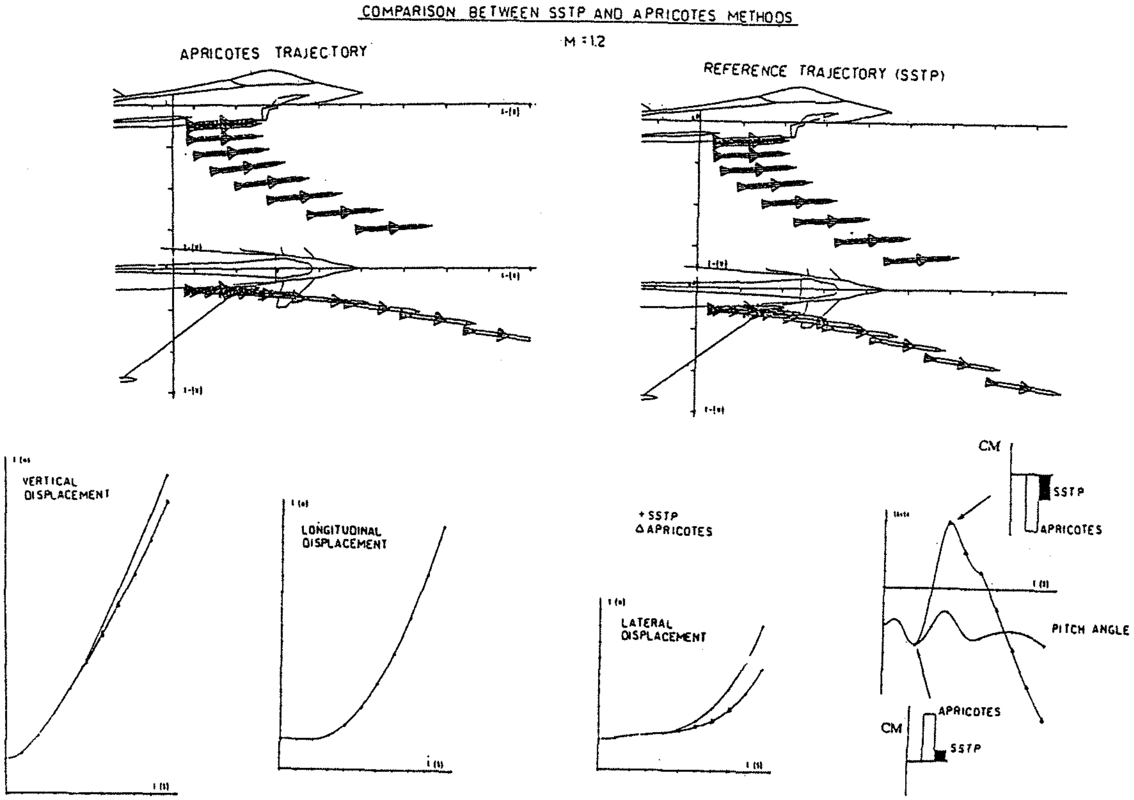
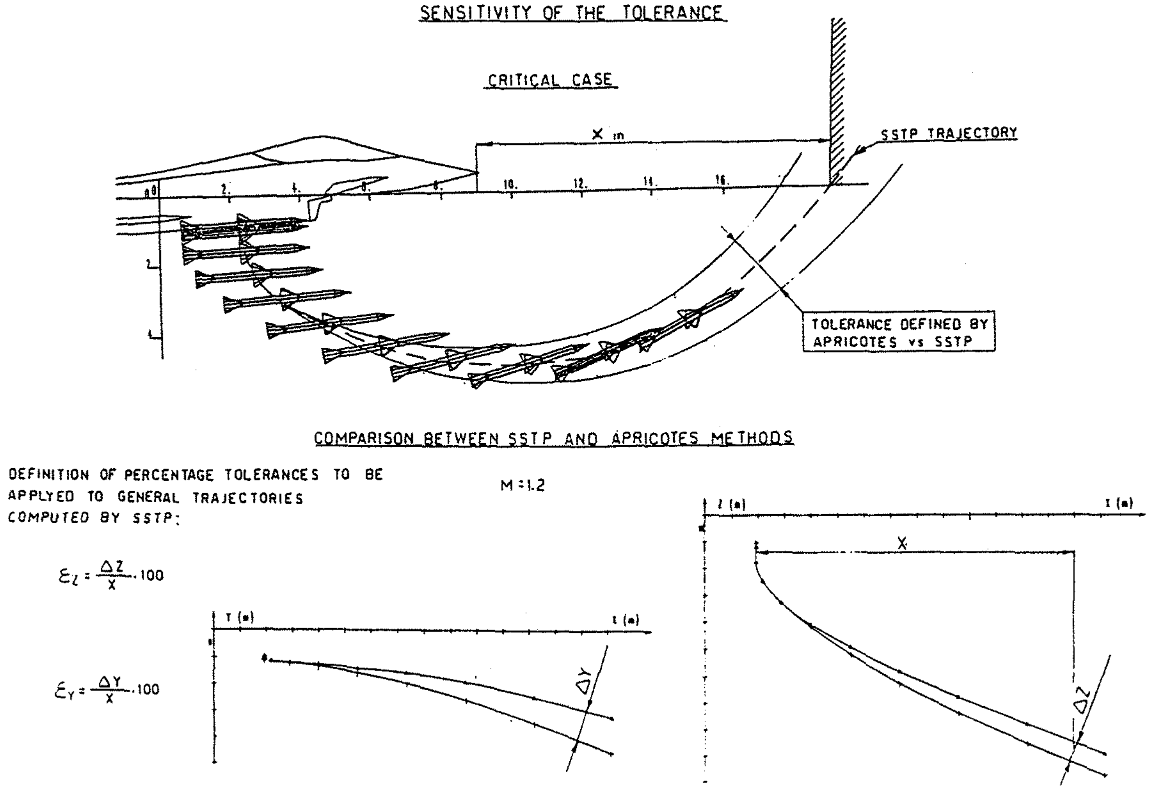


FIG.10

SSTP Vs APRICOTES: TRAJECTORY DIFFERENCES IN TERMS OF TOLERANCE



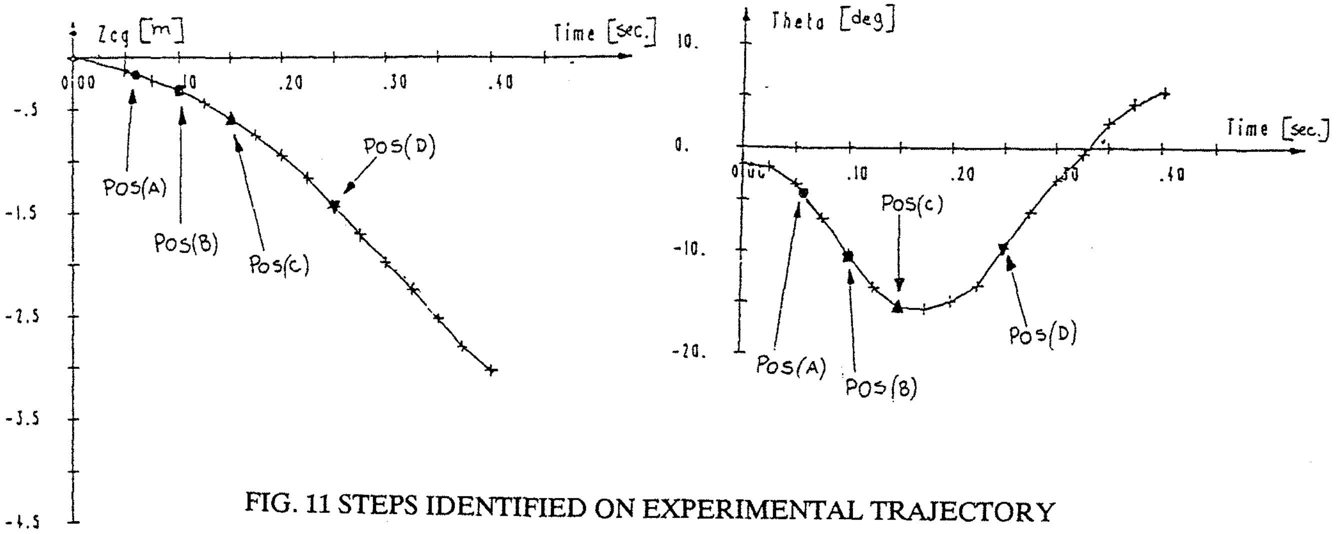


FIG. 11 STEPS IDENTIFIED ON EXPERIMENTAL TRAJECTORY

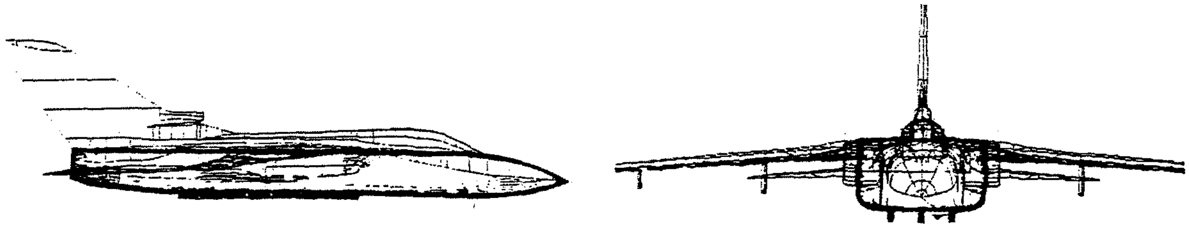


FIG. 12 AIRCRAFT MASTER GEOMETRY

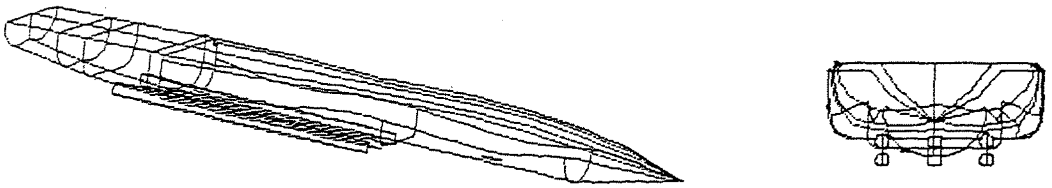


FIG. 13 SIMPLIFIED GEOMETRY

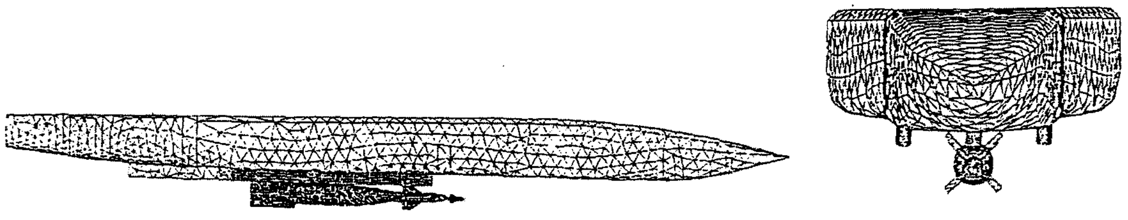


FIG. 14 EULER CODE SURFACE GRID

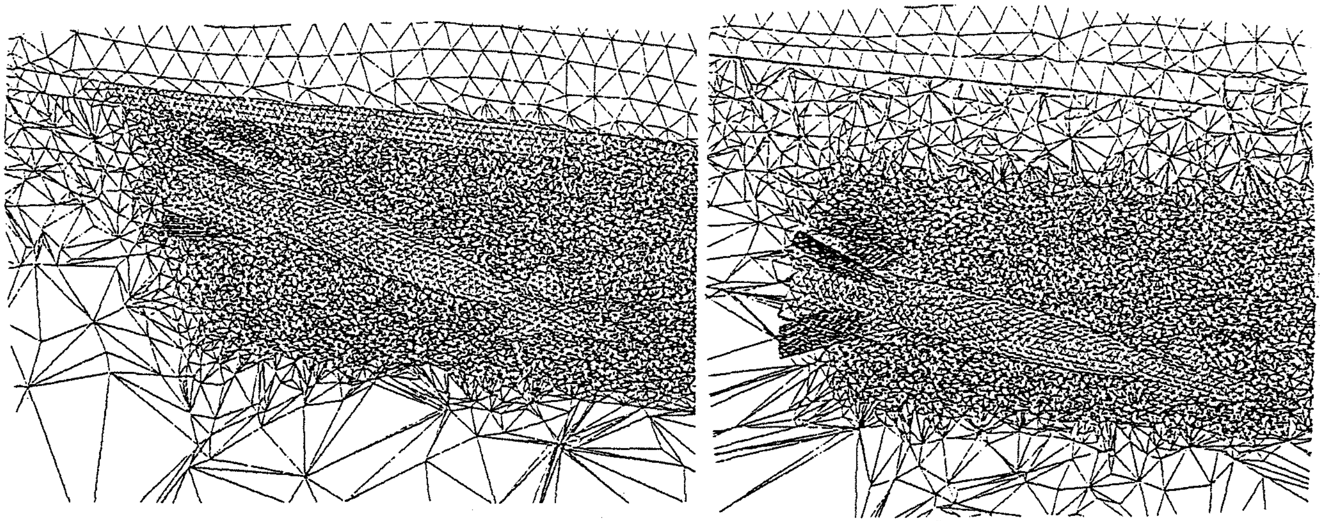


FIG . 15 DETAIL OF 3D MESHES FOR POSITIONS B AND D

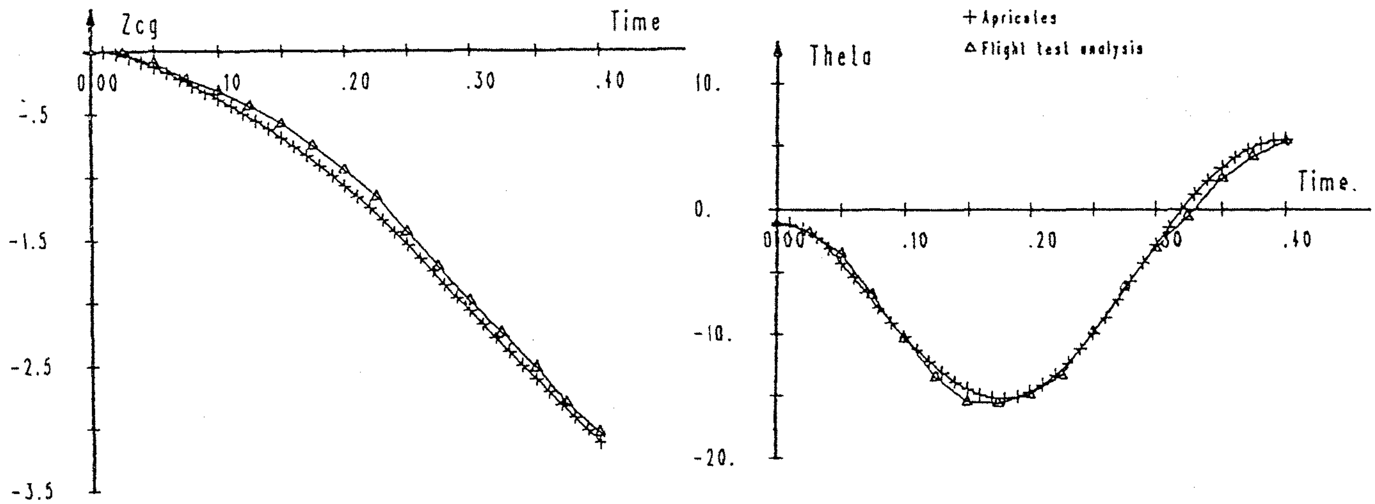


FIG. 16 COMPARISON BETWEEN FLIGHT TEST AND THEORETICAL TRAJECTORY