

# Aeroelastic Analyses in "PZL-Mielec" Using *MSC/NASTRAN*

Wojciech Chajec



Zakład Lotniczy "PZL-MIELEC" Sp. z o. o.

(Aircraft Factory "PZL-MIELEC"  
Ltd.)

ul. Wojska Polskiego 3, PL 39-300 MIELEC, POLAND,  
phone: (+48) 17-7887547, e-mail: chajec@rz.home.pl

## Abstract

Presented here is implementation of *MSC/NASTRAN* system in aeroelastic computation practice in "PZL-Mielec". This computation system is compared with our own old flutter calculation programs. Discussed are advantages and also difficulties caused overcoming of old habits and the fact that *MSC/NASTRAN* is an universal system not only for flutter calculation. PC programs which were created specifically to overcome the difficulties are presented additionally. A few interesting results of calculations are also showed.

## Contents

1. Short view on flutter calculation methods in "PZL-Mielec" before *MSC/NASTRAN* based on calculated (beam-like structural calculation model) or in GVT measured modes.
2. Implementation of *MSC/NASTRAN* system.
3. Description of additional programs for PC - useful for aeroelastic calculation in *MSC/NASTRAN*, prepared in "PZL-Mielec"
  - programs for natural mode and flutter mode animation and drawing
  - program for drawing and sorting flutter calculation results:  $g(V)$ ,  $f(V)$
  - graphic preprocessor for aerodynamic data generation and static pressure distribution drawing (for static aeroelasticity calculation)
  - some modification of *propf.for* program (in *propa.v68* - alter) for aerodynamic forces in whirl-flutter calculation
4. Examples of aeroelastic calculation in "PZL-Mielec" and problems
5. Conclusions

Trademarks are in *Italics* and listed at the end of this paper. Copyright © 1999 by Wojciech Chajec. All rights reserved. Wojciech Chajec, owner of the copyright to the work „Aeroelastic analyses in "PZL-Mielec" using *MSC/NASTRAN*" on this 20<sup>th</sup> day of March 1999, grants to The MacNeal-Schwendler Corporation a royalty-free, irrevocable, non-exclusive, worldwide licence to publish the work in MSC's proceedings for its 1999 Aerospace Users' Conference.

## 1. Short view on flutter calculation system used in "PZL-Mielec" before *MSC/NASTRAN*

The group of programs used for flutter calculations at "PZL-Mielec" in the 80's consisted of a few Fortran IV based applications initially run on *IBM-360/370* and later on PC. After switching to PC the system was substantially modified and some graphic programs were added (see also Figure 1).

*Programs used in PC flutter calculation system only (in alphabetical order):*

***APRMH.EXE*** - (optional) - distributed masses data approximation - FORTRAN 77, Microsoft Fortran Compiler, v.3.3 (1985).

***APRSC.EXE*** - stiffness data approximation - FORTRAN 77.

***DT.COM*** - plot \*.*z10* - files for plotter Roland (DXY - code) - Turbo Pascal v.3.

***KOS.EXE*** - program for geometry data verification; makes \*.*z10* - file for ***DT.COM***; FORTRAN 77.

***FLATH.EXE*** - flutter calculation: incompressible Theodorsen's strip aerodynamic theory for airfoil with (optional) control surface with (optional) tab, V-g method (K-method) of flutter equation solution; FORTRAN 77, Microsoft Fortran Compiler, v.3.3 with library ***flatippt.lib*** in MS-Pascal and Assembler.

***POSTH.EXE*** - natural vibration (frequencies and modes) calculation based on stiffness and mass data; aircraft: monoplane with classic, T, + or H - tailplane; FORTRAN 77, Microsoft Fortran Compiler, v.3.3 with library ***postippt.lib*** in MS-Pascal and Assembler.

***POSTM.EXE*** - natural vibration calculation (complementary way, Reference 5) based on (calculated or measured) natural vibration for alternate mass model (small alteration) of the same airplane (stiffness data without alteration) - FORTRAN 77.

***POSTR.EXE*** - natural vibration calculation (alternate way) based on results of ground vibration test (GVT) and theoretical model of mass distribution; with orthogonality proof and - if necessary - optional orthogonalization of measured modes (Reference 3,5; three methods of orthogonalization are possible) - FORTRAN 77.

***UBAHR.EXE*** - vibration mode calculation postprocessor - FORTRAN 77.

***WSPCCH.EXE*** - program to obtain selected portions of flexibility matrix (stiffness test simulation), calculation model as in ***POSTH.EXE*** - FORTRAN 77.

Programs ***APRSC.EXE***, ***WSPCCH.EXE***, ***APRMH.EXE***, ***POSTH.EXE***, ***POSTR.EXE*** and ***FLATH.EXE*** (*JG2-system* named) are made by group led by Prof. M. Nowak in IPPT PAN, Warszawa (Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw) with some modifications made in "PZL-Mielec" (Reference 1-3).

It is apparent that we can use calculated or measured free vibration modes for flutter computation. In many cases, for example: SZD-51-1 *Junior*, SZD-52-4 *Krokus*, KR-03A *Puchatek*, PW-5 *Smyk* - sailplanes; PZL - M20 *Mewa* (licensed version of Piper PA-34 *Seneca II*), PZL - M28 *Skytruck*, both methods were used. Based on GVT, computing of normal modes and flutter of airplane with different mass distribution is also possible (using ***POSTM.EXE***, see Reference 5).

Some of the added graphic programs after some modifications became useful also to analyze the flutter results from *MSC/NASTRAN*. These programs from PC flutter calculation

system, are listed below (in alphabetical order). User interface of *CAM.EXE* is in English. Manuals and user interfaces for all other programs are in Polish:

*CAM.EXE* - normal and flutter modes and GVT results animation - Turbo Pascal v.6; by W. Cerczynski.

*GLUGE.EXE* - tool (preprocessor for geometry) for *CAM.EXE* - Turbo Pascal v.6.

*GLUPO.EXE* - tool (preprocessor for mode shapes) for *CAM.EXE* - Turbo Pascal v.6.

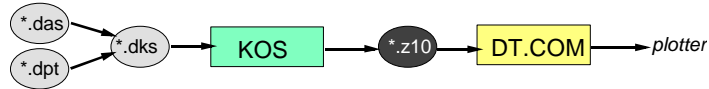
*RYSH.EXE* - GVT results proof and correction; GVT results, free vibration and flutter modes animation and plot - Turbo Pascal v.6.

*SOWY.EXE* - ordering of flutter results (also from \*.f06 - file from *MSC/NASTRAN*), damping versus speed V and frequency versus V diagrams with optional vectors of flutter modes draw; V is true (*TAS*) or equivalent (*EAS*) air speed; Turbo Pascal v.6.

*Files (more important, in alphabetical order):*

- \*.dam - distributed masses data for *APRMH.EXE* - text file.
- \*.das - geometry and stiffness data for *APRSC.EXE* - text file.
- \*.dfl - text data for *FLATH.EXE* and *UBAHR.EXE* (geometry of aerodynamic surfaces, selected numbers of natural vibration).
- \*.dks - text data for *KOS.EXE*; \*.dks = \*.das + \*.dpt without some data.
- \*.dpm - text data for *POSTM.EXE* (data of concentrated masses).
- \*.dpr - text data for *POSTR.EXE* (data of concentrated masses, geometry of pick-ups /sensors/ in ground vibration test /GVT/, orthogonalization data).
- \*.dpt - text data for *POSTH.EXE* - (concentrated masses data, frequencies of control systems).
- \*.dsi - topology of pick-ups /sensors/ in GVT - text file.
- \*.dcz - coordinates of pick-ups in GVT - text file.
- \*.dre - indications (accelerations similar to displacements) of pick-ups (in measured modes) - text file.
- \*.dub - complementary data for *UBAHR.EXE* (very small text file).
- \*.dws - text data for *WSPCCH.EXE* - (selected degrees of freedom).
- \*.f06 - results from *MSC/NASTRAN* (text file).
- \*.geo - geometry and topology for *CAM.EXE* - (binary file).
- \*.mod - displacements of plot nodes for *CAM.EXE* - (binary file).
- \*.wsi - topology of plot nodes - text file, result of *UBAHR.EXE*.
- \*.wcz - coordinates of plot nodes - text file, result of *UBAHR.EXE*.
- \*.wpo - displacements of plot nodes in calculated vibration modes - text files, results of *UBAHR.EXE*.
- \*.wub - results of *UBAHR.EXE*: frequency, modal damping and generalized mass for each natural vibration mode - text file.
- \*.wws - results of *WSPCCH.EXE* - (flexibility coefficients).
- \*.z8 - geometry and stiffness database (result of *APRSC.EXE*) - text file.
- \*.z9 - distributed masses database (result of *APRMH.EXE*) - text file.
- \*.z10 - plot-file in KONGSBERG-code.
- \*.z12 - interpolated results of natural vibration calculation - binary file.
- \*.z14 - modal mass matrices before, during and past orthogonalization - text files.
- \*.z15 - unordered or ordered results of flutter calculation (text file, which each record containing: reduced frequency - as parameter for K-method, and - for every flutter eigenvalue: speed, frequency and damping).
- \*.z17 - results of flutter calculation - flutter modes - text file.

Geometry data verification:



Flexibility coefficients computation:



Flutter calculation main flow diagram:

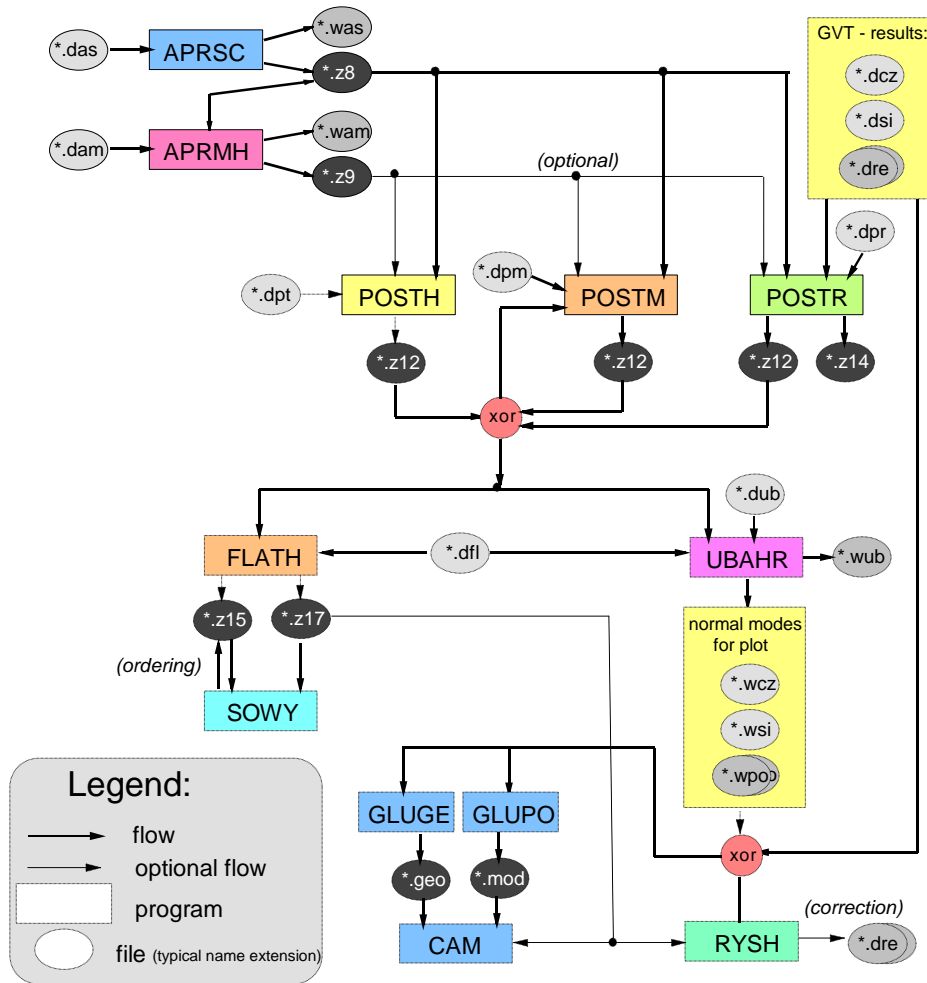


Figure 1. Flow diagrams of old flutter calculation system used in PZL-Mielec (on PC's beginning from IBM AT 80286 with coprocessor)

As an example is symmetric flutter calculation of PZL - M28 *Skytruck* based on GVT. Using *POSTR*, *POSTM*, *FLATH* and other programs, the best value of mass balance in wing outer part is determined.

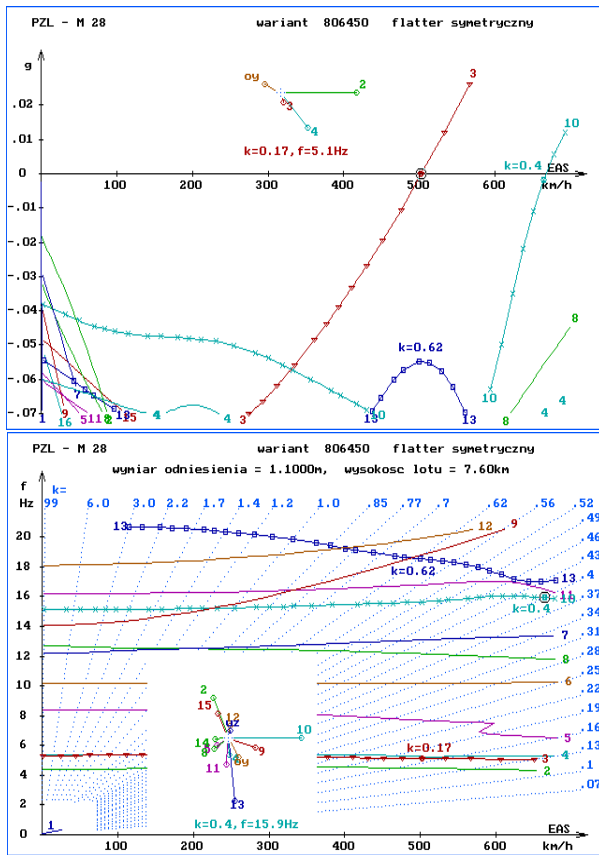


Figure 2. Flutter damping and frequency versus speed plots. For selected calculation points the phase diagrams are presented (by *SOWY.EXE*).

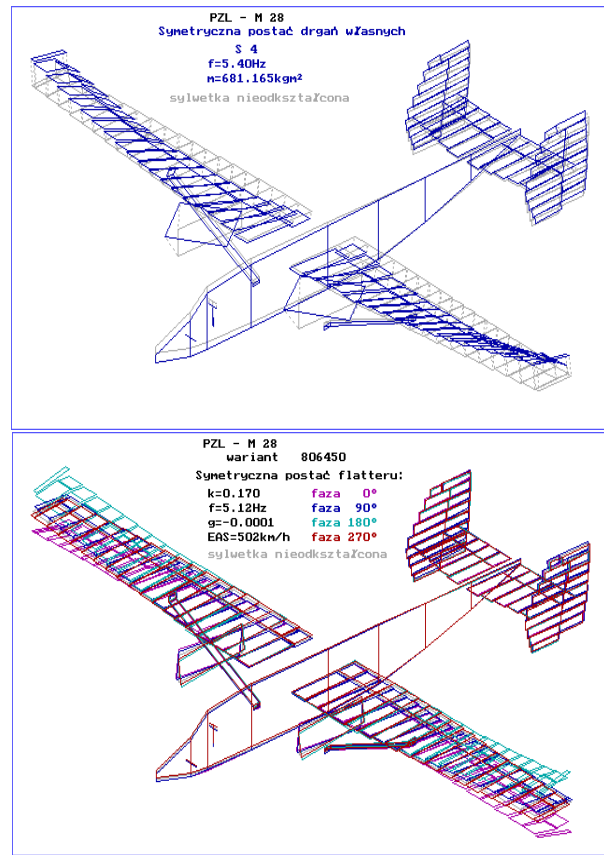


Figure 3. *RYSH.EXE* program results. Free vibration mode plot (above) and wing flutter mode plot (below)

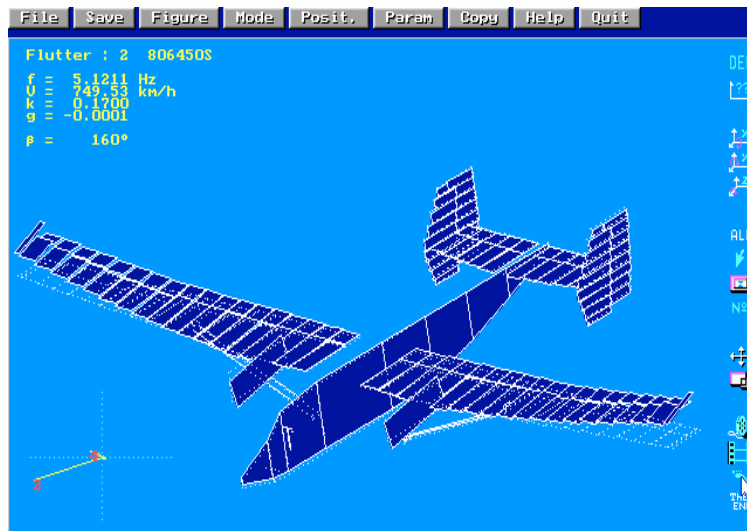


Figure 4. Flutter mode animation in *CAM.EXE* program.

## 2. Implementation of *MSC/NASTRAN* system

Since 1993 the system used in "PZL-Mielec" for structural and aeroelastic analyses is *MSC/NASTRAN* with *MSC/XL* pre- and postprocessor. It works with *Sparc*-compliant *Marix Workstation* with *SunOS Release 4.1.3* and *OpenWindows Version 3*. This workstation is connected to 3 PC's with Microsoft Windows as X-terminals.

The most obvious action was to compare both systems and to write program *JG2N.EXE* (in FORTRAN 77) that converts data from old flutter calculation system *JG2* to *MSC/NASTRAN* bulk data file (structural model only without aerodynamic data).

### *Interface to NASTRAN:*

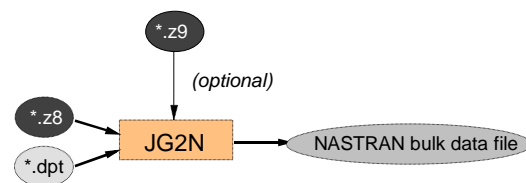


Figure 5. Flow diagram of data converted from old flutter calculation system to *MSC/NASTRAN*

Our old flutter calculation system was constricted to small models of conventional airplane only. Troublesome was also accounting for airplane control system elements inertia especially important in flutter calculation of sailplanes and light airplanes.

*MSC/NASTRAN* system does not impose such limitations. It also offers a few aerodynamics models, also accounting for air compressibility.

The results of calculation in both systems for the same dynamic models (made for Polish 15-meter class sailplane SZD-56 *Diana*) are similar.

Unfortunately using *MSC/NASTRAN* system we can not utilize in flutter calculations vibration modes measured in GVT (as using *POSTR.EXE* or *POSTM.EXE* programs). Question: Is it possible (for example using *DMAP* - language) to use measured modes in *MSC/NASTRAN* flutter calculation?

Additionally accessible *MSC* software is not very convenient to work out results of aeroelastic analyses. In "PZL-Mielec" the study of the results of computation is PC based. Graphic representation of calculation results from *MSC/NASTRAN* is created by using our own programs, including software used in old flutter calculation system (see above and flow diagram below) and programs written specifically for this reason discussed in next chapter.

### 3. Additional programs for PC - useful for aeroelastic calculation in MSC/NASTRAN, prepared in "PZL-Mielec"

PC based programs special for flutter analysis support in MSC/NASTRAN (in alphabetical order)

**C2Q.EXE** - converts aerodynamic boxes from MSC/NASTRAN \*.f06 - file (SOL 145 with PARAM OPPHIPA=1) to QUAD4-elements. Makes \*.dat (grid and element definition) and \*.ext (natural mode shape, grid displacements) files for MSC/XL; Turbo Pascal v.6; by W. CERCZYNSKI .

**F06.EXE** - selects displacements, forces or pressure on aerodynamic boxes from MSC/NASTRAN \*.f06 - file (SOL 145 or 144 with PARAM OPPHIPA=1) to MCA.EXE program - Turbo Pascal v.6; by W. CERCZYNSKI .

**MCA.EXE** - aerodynamic data for MSC/NASTRAN graphic editor capable of drafting pressure distribution and forces on aerodynamic elements drawing - Borland Pascal v.7; by W. CERCZYNSKI .

**TRANRYS.EXE** - vibration mode calculation postprocessor - makes files \*.wsi, \*.wcz, \*.wpo (for RYSH.EXE and CAM.EXE) based on file \*.f06 from normal modes calculation (SOL 103) in MSC/NASTRAN; Turbo Pascal v.6.

**WYSTA.EXE** - selects static aeroelasticity results from MSC/NASTRAN \*.f06 - file (SOL 144) to a text file, for example for Grapher - Turbo Pascal v.6.

#### Postprocessors for NASTRAN:

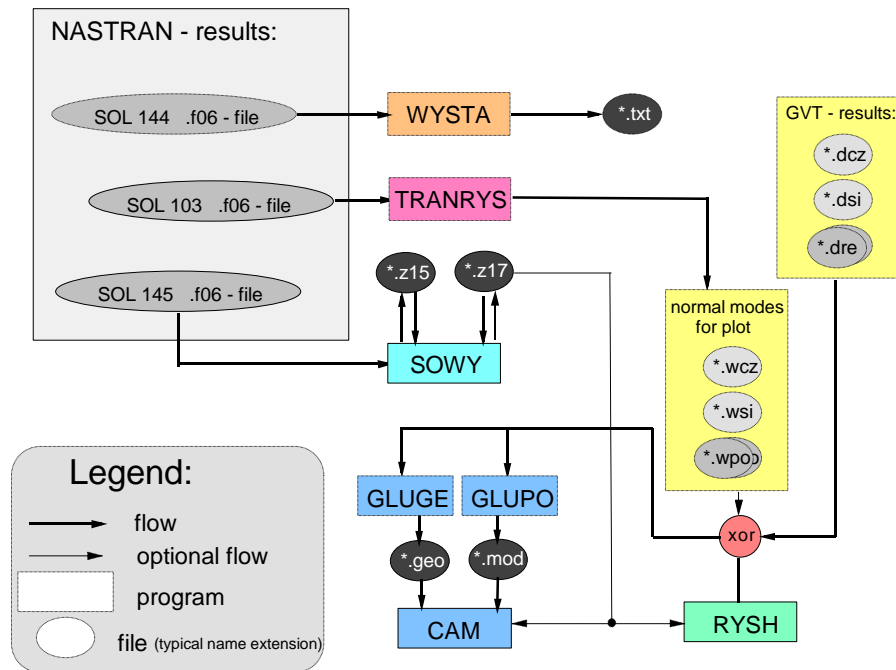


Figure 6. Flow diagram of selected PC programs for MSC/NASTRAN aeroelastic results drawing and animation

In "PZL-Mielec" we also conducted whirl-flutter calculation of PZL - M28 Skytruck with two turbo-prop engines. These calculations were done by using our own program in Turbo

Pascal (restricted to four degrees of freedom only, made by J. Pietruszka) and also in *MSC/NASTRAN*, using *ALTER propa.v68* and program *propf.for* for gyroscopic and aerodynamic forces determination. Results of both programs are similar for simple calculation models with four degrees of freedom. Please note that our program was faster in this case. However using *MSC/NASTRAN* gave us the possibility of conducting flutter calculations for the whole airplane with gyroscopic and aerodynamic forces appearing on propeller.

In order to conduct whirl-flutter calculation in *MSC/NASTRAN* program *propf.for* had to be used. Thanks to some optimization we could compile the program using FORTRAN 77 Microsoft Fortran Compiler, v.3.3 (1985!). Next to the version for British units (named *PROP.EXE*) *PROPM.EXE* for metric units was created. These programs need only 220 KB operating memory.

#### 4. Examples of aeroelastic calculation in "PZL-Mielec" and problems

##### *Aeroelastic analysis of PZL - M 26 „Iskierka” („Airwolf”)*

PZL - M26 *Iskierka* (*Little spark*; in USA offered as *Airwolf*) is piston two-seater for utility and aerobatic usage. Beam-like flutter structural half-span model of this aircraft was transferred by *JG2N.EXE*. During calculation of aileron effectiveness (static aeroelasticity) we created drawings of air pressure distribution using *MSC/NASTRAN* SOL 144 and later *F06.EXE* and *MCA.EXE* programs.

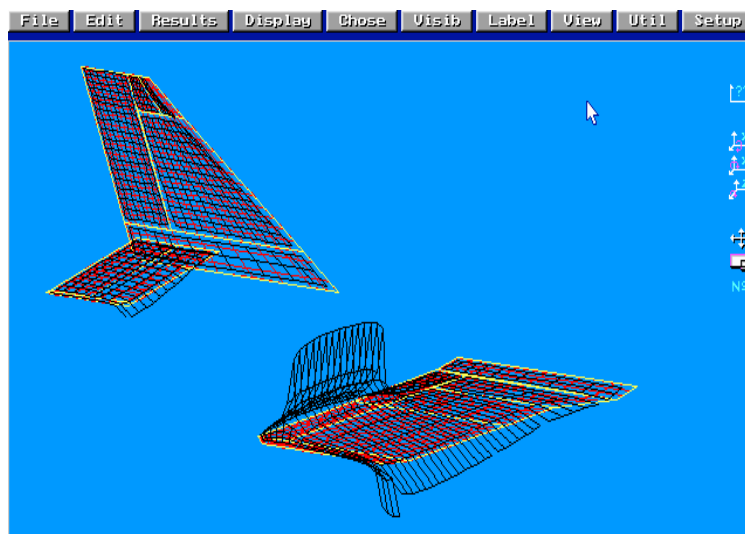


Figure 7. Air pressure distribution in aileron effectiveness calculation (by *MCA.EXE*).



## Flutter calculation of agricultural airplane PZL - M18B „Dromader”

The agricultural airplane PZL - M18B *Dromader* is the only plane, for which full span calculation model was used in the flutter calculations. Beam-like models of wing, tailplane, flaps and aileron were transferred by *JG2N.EXE*. Later fuselage frame control systems and balance tabs models were added to the model. Trimming tabs were modelled as rigid. All ruder and elevator tabs are out of basic tailplane chord (taken into account in aerodynamic model).

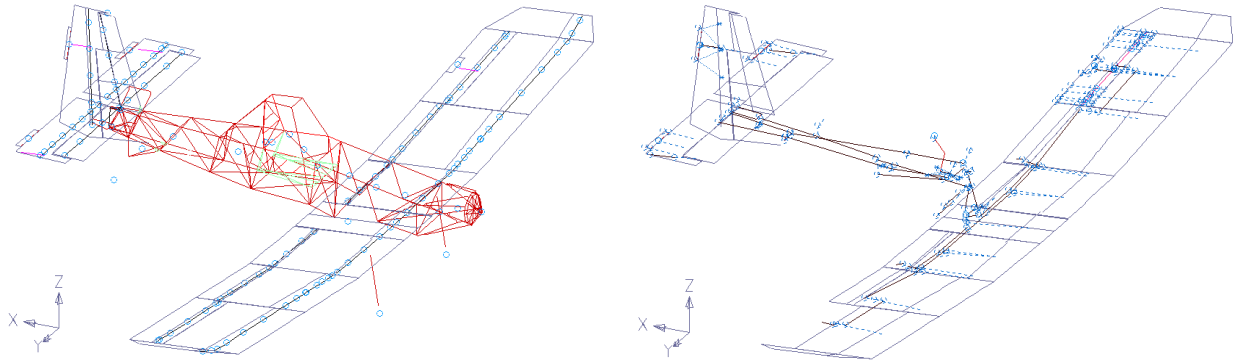


Figure 8. Calculation model of M18B in MSC/XL: without rigid elements and control systems (left) and control systems with left aileron and PLOTEL element only (right).

A full span calculation model causes considerable increase in time and system resources. For this reason, initially in accordance with (Reference 7), Page 149: (in flutter analysis) ... *more than one aerodynamic theory can be present in the same aerodynamic model*, we tried to combine *Doublet Lattice* and *Strip* aerodynamic models. It is yet impossible (in MSC/NASTRAN v.68.1 error 9126 appears).

Connecting (a surface spline) between structural model and CAERO1 aerodynamic elements was checked by comparing movements of structural and aerodynamic models using MSC/NASTRAN with OPPHIPA=1, later *C2Q.EXE* and MSC/XL.

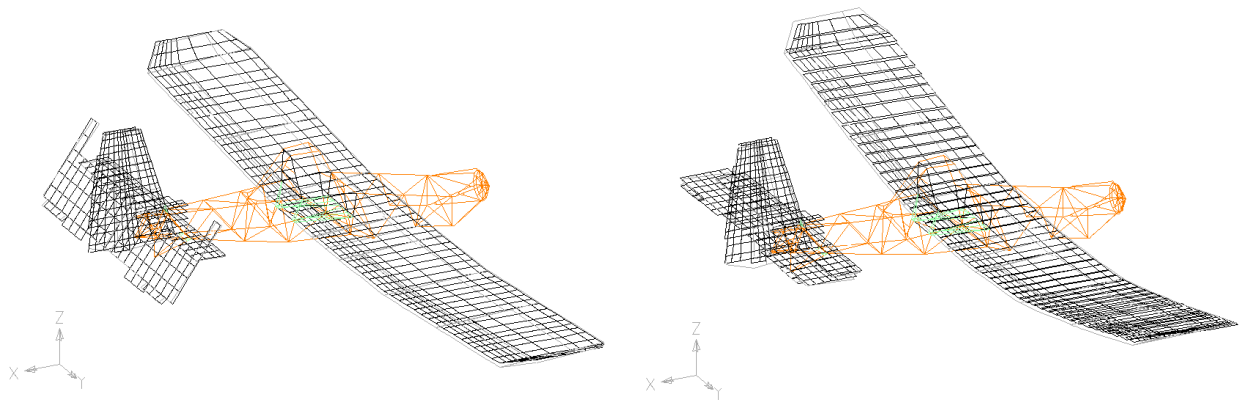


Figure 9. Proof of spline interpolation connecting structural and aerodynamic models (by *C2Q.EXE* and MSC/XL). Normal modes: elevator rotation (with balance tabs; left) and first wing bending (right).

## Flutter calculation of ultralight biplane FK-12 „Comet” from Germany

The ultralight (up to 450 kg) biplane FK-12 *Comet* constructed and commissioned by B&F GmbH (Germany) is made in Krosno (Poland). German rules for this category of airplane (*BfU*) do not require flutter analysis. Only the constructor demanded them. Calculation model is a half span model. The model of fuselage frame is made as symmetrical using MPC's, some BAR's with half stiffness and PLOTEL. Shown are results of symmetrical flutter calculations with lowered stiffness of flaperon control system, without flaperon mass balance.

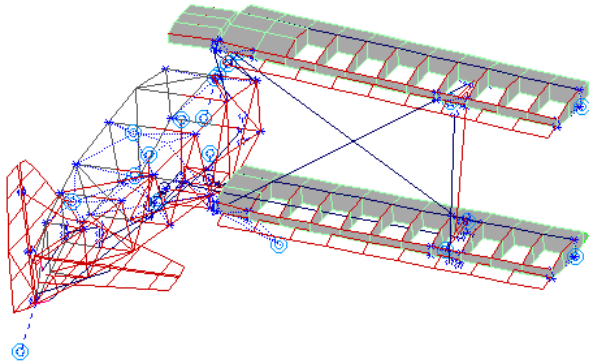


Figure 10. Calculation model of FK-12 (by MSC/XL).

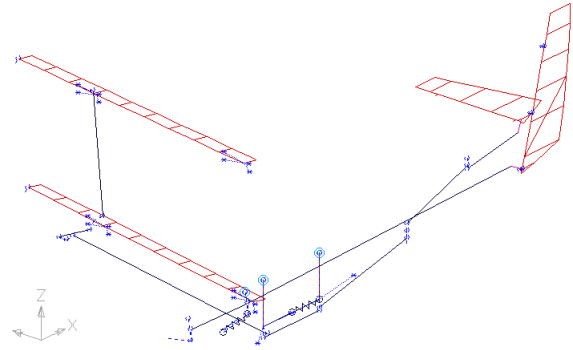


Figure 11. Model of flaperon, elevator, ruder and control systems.

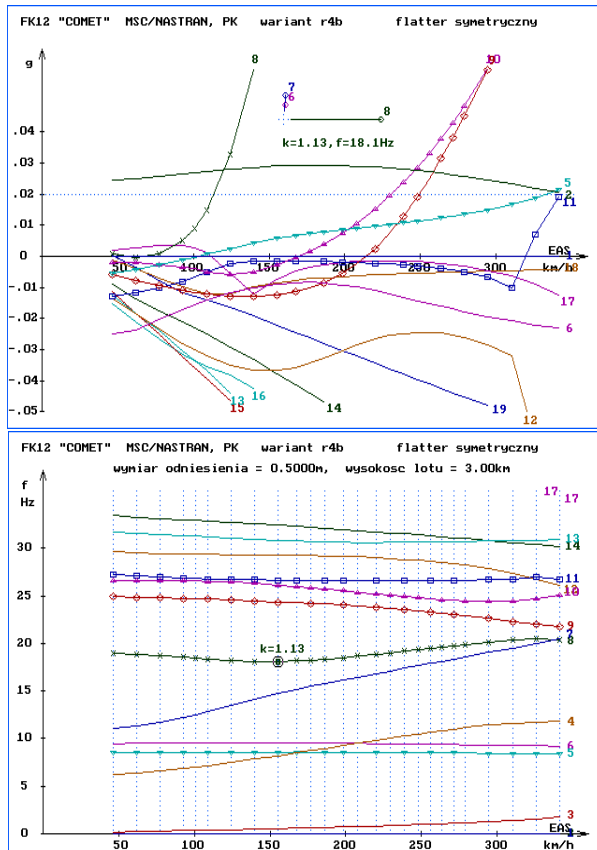


Figure 12. Flutter results for too small stiffness of flaperon control system (SOWY.EXE).

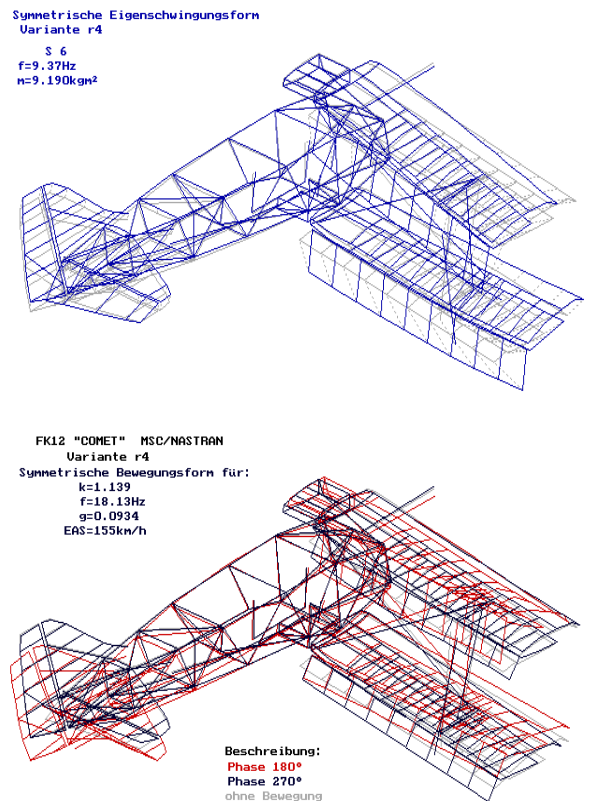


Figure 13. Normal mode typical for biplane (above) and wing/flaperon flutter mode (curve 8; below).

## Problems with flutter calculations for Mach number adequate to speed

In PK flutter equation solution method the velocity is an independent parameter. It is apparent here, that it would be possible to give (at selected flight altitude) corresponding Mach number ( $Ma$ ) to every flight speed. However, it appears not to be worth to use interpolation of aerodynamic matrix in relation to Mach number, because it shows that this interpolation is brought to staircase function of  $Ma$ . (in used version 68.1 of *MSC/NASTRAN*). It is more effective (shorter time and small memory consumption) to conduct the calculation of consecutive values of Mach number as separate tasks.

An interesting outcome resulted from flutter calculations for turbo-jet trainer PZL I-22 *Iryda* with Fowler flaps (Ref. 8) shown on the drawing to the right. However all curves 9 (wing torsion with flap rotation, frequency ca. 27 cps) when  $Ma = const.$  are crossing axis  $g = 0$  (flutter would be possible for speed greather than „critical”), line connected the points (great circles), where Mach number is adequate to flight speed, does not cross  $g = 0$  (flutter impossible). These are just theoretical observations because maximum speed of this aircraft with flaps extended is significantly below „critical” values.

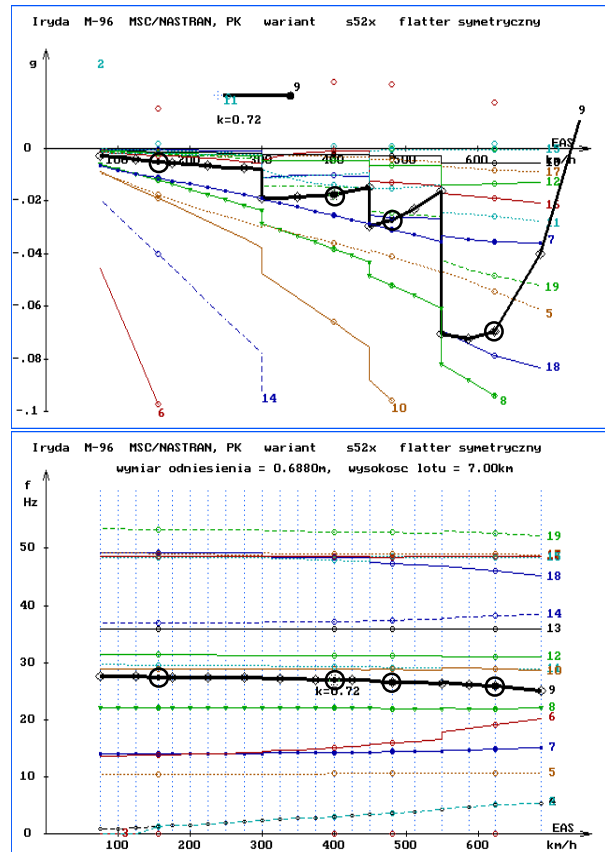


Figure 14. Calculation results for Mach numbers:  
 $Ma = 0.25$  (equivalent to  $EAS = 195$  km/h) for  $EAS < 278$  km/h  
 $Ma = 0.5129$  (equiv. to 400 km/h) for  $278 < EAS < 440$  km/h  
 $Ma = 0.6155$  (equiv. to 480 km/h) for  $440 < EAS < 552$  km/h  
 $Ma = 0.8$  (equivalent to  $EAS = 624$  km/h) for  $552$  km/h  $< EAS$

## Conclusions

Using presented PC-based programs one can easily interpret the results of flutter calculations. Particularly important is the capability of flutter modes animation. The *MSC/NASTRAN* flutter calculation results after *SOWY.EXE* postprocessing (and also free vibration mode calculation results after *TRANRYS.EXE*) are saved in small files.

Speed on horizontal axis for both diagrams  $g(V)$  and  $f(V)$  is an equivalent air speed ( $EAS$ ) chosen rather than  $TAS$  (true air speed) because the  $EAS$  is similarly to instrumental air speed ( $IAS$ ) and the diagrams are then simpler to interpret. In addition, the change of flutter critical speed with altitude is slower in  $EAS$  than in  $TAS$  (Reference 6; when for determination of aerodynamic forces the simple quasi-stationary theory would be used, the calculated critical flutter speeds  $EAS$  would be independent of altitude).

For classic control systems (non fly-by-wire, without actuator) it is necessary to take control elements (e.g. stick, pedals, pushrods) inertias into account (Reference 6). System *MSC/NASTRAN* is here very convenient.

## Acknowledgments

This paper is written with permission of *Zakład Lotniczy „PZL-Mielec” Sp. z o. o.* Calculation results of ultralight biplane FK-12 *Comet* are included with the permission of *B&F Technik Vertriebs GmbH, Speyer/Rhein, Germany*

### *Applications used to create this publication*

*Microsoft Word*, v. 6.0a (PL)

*Grapher for Windows* (SN: GW-9521) of Golden Software, Inc.

*Micrografx Designer* 4.01 PL.

*Screen Thief* v. TD 1.01, (1993, shareware, trial), Nildram Software, GB, phone (0442) 891331, fax (0442) 890303

### *Trademarks*

*NASTRAN* is a registered trademark of NASA. *MSC/NASTRAN* is an enhanced, proprietary version developed and maintained by MacNeal Schwendler Corporation.

*Marix Workstation* is a registered trademark of Aries Research, Inc.

*Sun, SunOS, NFS* and *OpenWindows* are trademarks of Sun Microsystems, Inc.

*SPARC* is a registered trademark of SPARC International, Inc. Products bearing the *SPARC* trademark are based on an architecture developed by Sun Microsystems, Inc.

*Micrografx* is a registered trademark, *Designer* is trademark of Micrografx, Inc.

*Microsoft* is a registered trademark, *Windows* and *MS-DOS* are trademark of Microsoft Corp.

*Turbo Pascal* and *Borland Pascal* are a registered trademark of Borland International, Inc.

*Grapher* is trademark of Golden Software, Inc.

## References

- (1) Nowak, M., „A New Method of Calculating the Natural Vibrations of a Free Aeroplane”, *ICAS Paper* No 72-05, Amsterdam, 1972
- (2) Nowak, M., Potkanski, W. „Metodyka analizy flatteru samolotów lekkich” (in Polish, „Flutter Analysis of Light Aeroplanes”), *Prace Instytutu Lotnictwa*, nr 65, Warszawa 1976
- (3) Baruch, M., „Proportional Optimal Orthogonalization of Measured Modes”, *AIAA Journal*, Vol.18, No 7, 859-861, 1980
- (4) Rodden, W. P., Rose, T. L. „Propeller/Nacelle Whirl Flutter Addition to MSC/NASTRAN”, Paper No. 12, *Proceedings of the 1989 MSC World User’s Conference*, Universal City, CA, March 1989
- (5) Chajec, W., „Flutter Calculation of Light Airplanes Using Results of Ground Vibration Test” (in Russian), *IV Aerospace Conference Countries of Council of Mutual Economic Assistance*, Budapest, November, 1989
- (6) Chajec, W. C., „Critical Flutter Speed of Sailplanes Calculated for High Altitude. Examples of Computation”, *Technical Soaring*, Vol XVIII, No. 3, 69-72, 1993
- (7) *MSC/NASTRAN Aeroelastic Analysis. User’s Guide. Version 68*, W. P. Rodden, E. H. Johnson, The MacNeal-Schwendler Corporation, Los Angeles, CA
- (8) Chajec, W., „Wpływ założonej liczby Macha na wyniki obliczeń flatteru z wykorzystaniem poddzwiekowej metody warstwy podwójnej” (in Polish, „The effect of intended Mach Number on Flutter Calculation Results Using Doublet Lattice Subsonic Method”, *II Konferencja Użytkowników Oprogramowania Firmy MSC, Warszawa (II MSC-Software User’s Conference, Warsaw)*, December, 1997