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PROGRAM PRAGTIC IN RESEARCH, ENGINEERING PRACTICE AND COMPETITIVE ENVIRONMENT

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PRAGTICA

(PRAGTIC IN APPLICATION)

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1 SCIENTIFIC AND/OR TECHNICAL QUALITY

1.1 CONCEPT AND OBJECTIVES

1.1.1 THE IDEA

A use of the finite element analysis (FEA) in conjunction with created standards or gathered experience allows design and production of new products in much higher rate. The use of FEA tools generates new components and machines, which are safe from the point of view of the static analysis. We are in a state, where the matching of the product's utility value with its fatigue properties can be the most important key to the game.

A lattice work, which used to be so popular among aircraft structures in the beginning of the 20th century, is too often obsolete today. As the new structural parts are designed, a clearly visible trend to save the space, weight or financial demands of the production by producing complex shaped components can be seen. The original methods describing the change of fatigue properties of beams with particular notches by introduction of notch factors derived from nominal stresses are relicts of the old times. Simply, the isolated beams are not very often today. But, the old methods still remain to be the most often used tools in the industrial practice.

The structural analysts got a very powerful tool in the finite element method. They can describe relatively accurately local loads anywhere on the structure. **The introduction of the FEM into the common engineering practice simplified development and design of new structural parts or units and sometimes allowed a decrease of necessary static tests. It is legitimate that also the fatigue analysts claim that they should get some advantage from this wonderful tool.** The massive invasion of hardware joint with accelerated increase of computational speed led to increasing complexity of fatigue life calculation schemes, which are today developed. The desired goal is to integrate the new fatigue calculation capabilities as seamlessly as possible with the FEA, so that the whole pre-design, design and even the prospective experimental certificate could be run on a virtual prototype existing only at the computer's hard disc.

There is a plenty of fatigue post-processors of the FE-analysis available on the market. Links to many of them can be found at http://www.pragtic.com/links.php, but it is very well possible that more of them exist. There is the strong pentad of MSC.Fatigue, FE-Fatigue, Fe-Safe, LMS.Virtual Lab c. Durability and FemFat, but there are also other low-cost products and there are even some purely academic software pieces.

As regards the commercial products, they are competing one with another. This could be probably the reason, why the producers often try to put on the market solutions, which are nicely integrated to the software, can be potentially checked with the experiments, but the user gets no information about the degree of their reliability. **There is no independent organization that would analyze properties of the fatigue software available on the market.** The fatigue analysis is very complex and the physical base of the methods is often only empirical (not as it is by the linear FEA). There are also many influences, which are not sufficiently covered even in the experiments.

Commercial tools able to do a fatigue analysis on FE-calculation results do not have a very long history. The negative aspects related to their use are:

- high price;
- quite high annual maintenance fee to ensure delivery of all actualizations (absolutely necessary due to the rapid development of these SWs);
- unsatisfactory lack of openness and description of implemented methods and the way of implementation itself;

- insufficient information on the use of implemented methods under particular service conditions of real structures;
- inability to modify the source code of the program to implement own findings;
- insufficient number of expert users;
- availability to users who have little expertise in fatigue analysis and little awareness of its limitations.

Project **PragTic** was started by Jan Papuga during his work on the PhD thesis. It subsequently grew into the current PragTic v.0.2 betaE version able to process FE-data or isolated points by a multiple of different computational fatigue methods. The program and other information on the whole project are available on website http://www.pragtic.com/program.php. PragTic is distributed as a freeware and its users are people working either in research or in industry (see http://www.pragtic.com/users.php).

Except for the research itself, the other main reason for its programming from the very start was the attempt to systematically verify commercially applied solutions. The research practice is too scattered and too often we see inventing of new bright analysis methods, while the previous ones have not been wholly checked yet. Moreover, there is no supervisor that would examine really thoroughly how the commercial implementations behave under specific conditions and given inputs. **Because the software producers disclaim any warranty for the use of the software they produce, the main burden of the proof of its functionality lies on its users. Such a practice either places great demands on the users or leaves them with a great, expensive and non-verified tool in hands. It is no wonder that the most of the users of the commercial fatigue tools belong to large companies. Due to the points mentioned above, the commercial fatigue software is not suitable for small or medium size enterprises.**

The companies and universities joint in this research consortium would therefore like to set one of its goals to an extensive comparison of commercial and non-commercial fatigue tools available within it.

These are:

Evektor (CZ) & all other	PragTic
Brno University of Technology (CZ)	MSC.Fatigue
Czech Technical University in Prague (CZ)	Fe-Safe
Fatec Engineering (NL)	fFatigue
SKODA VYZKUM (CZ)	FemFat
VCA (CZ)	WinLife

PragTic freeware is available to any participant and its source code will be provided within the consortium under the condition, that it will not be further distributed as a whole, in parts or in any modification.

PragTic is currently focused above all on fatigue induced by multiaxial loading. Some of PragTic's results are already available in the FatLim database (see please http://www.pragtic.com/experiments.php), which uniquely compares prediction capabilities of 18 different calculation methods focused on high-cycle fatigue solution under multiaxial loading at the fatigue limit. **It clearly documents that the most of the commercially implemented methods of this category are not suitable for common multiaxial solution.**

We nevertheless feel that the current focus is too narrow for a software tool equipped with such a complex inner structure. The mastered management of FE-data allows implementation of solutions used in other problems common to fatigue computations. It also provides a suitable base that can be used for further quick fatigue or FE-post-processing implementations by any interested body.

It should be noted here, that as the computational methods tend to complicate and sophisticate **the automated computer solution is the only possibility if any more extensive testing of new methods should be done**. If the computer solution has process the FE-structure simultaneously (what should be a necessary condition e.g. for testing of notch effect, welds, etc.), **the amount of programming work**

associated with it could substantially exceed the amount of work related to the research itself. Possibility that more research bodies could work on one common prepared SW platform belongs to major advantages of the presented application.

On the other hand, Evektor is a design office with a direct link to manufacturing of its designs realized in Evektor-Aerotechnik, which is an affiliated company. Evektor currently focuses on two major projects - a four seat single engine VUT100 Cobra and nine seat passenger or cargo two engine turboprop EV-55. The fatigue analysis is a necessary part of any design project in such a scale. Evektor's size and capability would be much better used if the FEA-results post-processing link had included also some fatigue solver. Due to the state-of-the-art described above, Evektor representatives expect that the investment into PragTicA project with clear documentation of the experiments done on materials used within Evektor's airplanes makes more sense then the purchase of any existing commercial system.

1.1.2 TOPICS ADDRESSED

As regards the topics, which are addressed by the call and which PragTicA project fulfils, they are analysed in the text that follows in this section:

ADVANCED MODELLING AND SIMULATION TOOLS TO INCLUDE 'VIRTUAL REALITY' IN SUPPORT OF DESIGN AND 'VIRTUAL PROTOTYPING'

The present state in the professional design of engineering structures is based on two already quite well linked levels – 3D CAD systems for the component design and FEA-solver accompanied by the link item itself – a suitable FEA preprocessor. The analysis of results done usually in a native FEA post-processor allows evaluation of actual load levels that could endanger correct function of the component analysed under static load either by too large displacements or too high stresses.

FEA fatigue postprocessors are the next level necessary to make the design process really virtual. We have dealt with the negatives related to their use in the list in Sec. 1.1.1. Our project should respond to the most of those negative points. The problem of highest priority in our opinion is too benevolent practical use of those not adequately verified software tools with unskilled users. If this state continues it can eventually induce substantial losses on equipment, machines or even casualties.

The solution we propose is based on accessibility of PragTic. The freeware type of licence helps the distribution of PragTic but we would like to go even farther. We are in the point when we offer to share also its source code, although at start only among partners of this project. Our premise is that it does not matter if the commercial tools copy our approaches or solutions. Such their acceptance would be in fact advisable. We see the future of commercial systems and the base for their competition in the maximum speed of calculation and quality and interactivity of the user interface. The methods themselves should not be so decisive.

The reason of PragTicA is not to introduce PragTic to the commercial market. This would need too large investments. But the joint work of interested research and engineering institutes can breed an independent fatigue tool that could be used even by SMEs, which are not today able to finance purchase of current commercial tools. Our combined force will document current properties of existing fatigue tools substantially better and is able to propose alternate solutions.

DEVELOPMENT OF ADVANCED METHODS AND COMPUTATIONAL TOOLS IN THE FIELDS OF STRUCTURAL ANALYSIS

Fatigue analysis is a subspace in the structural analysis. All the WP2-WP6 are fully related to verification of existing computational tools, different calculation methods and their improvement. The fulfilment of this topic is unquestionable.

The virtual design topic joint with our focus concerning fatigue post-processing of FEA should give clear notion about positives coming from PragTicA realisation as regards the necessity of experimental testing. Possibility to remove the necessity of at least part of fatigue related experimental work while maintaining good ratio of strength to weight is the very positive outcome related to the work planned.

The other advantage related to PragTicA results is that we are de facto realizing at least a part of the experiments that should do anybody who wants to use contemporary fatigue solvers. The scale of planned dissemination is set in such a way so that all relevant results of our testing were accessible to any interested engineer or researcher. Thus we are minimizing purchase costs of any engineering or industrial company potentially interested in a purchase of a commercial system, because:

1. we plan to show quality of individual types of solutions implemented in different fatigue solvers – i.e. the user knows what he is buying;
2. he gets some image from published data, how the methods used in his chosen software behave under given conditions – he shouldn't blindly believe that he gets perfect results.

The consortium de facto acts as an organization for consumers' protection with a very specific target group.

1.1.3 OBJECTIVES

The major partial goals set nowadays in the project are:

1a. Learning the consortium participants to work with PragTic and modify or develop its source code if necessary (WP1).
1b. Establishing of the direct link to the dominant FEA-solvers (WP1)
2. Analysis of notch effects (WP2)
3. Analysis of multiaxiality effects (WP3)
4. Analysis of welded structures (WP4)
5. Analysis of riveted structures (WP5)
6. Analysis of composite structures (WP6)
7. Systematisation of the research and the evaluation results attained (WP7)
8. Dissemination of attained results to scientific and engineering public (WP8)

1.2 PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1 WP1 - PRAGTIC WITH ITS SOURCE CODE FOR FRESHMEN?

The contemporary practice in the development of fatigue solvers is based on the activity of the software producer above all. The company either does its own research in the search, which are the usable solutions for the implementation or collaborates with some university or research company, where it see such a collaboration (the check of potential methods or even the implementations) as more straightforward (i.e. cheaper)**. The decision what to implement is thus made by a very limited number of experts, checked by managers (non-expert) and finally realized – all these activities in secrecy so that the other competitors on the market have not know what is being prepared.**

There is some **conservatism** within the implementations. First, the users are engineers above all, not the researchers. Thus there is strong requirement to implement well known methods, which the nowadays engineers could meet already when they were at the university. Moreover, as the research practice and verification of individual methods is discontinuous, results of the older methods are usually better covered in the scientific papers.

The age of the calculation method and even the extent of its publicity are not the right evolution criteria nevertheless. The good example is the behaviour of Findley or Dang Van methods in FatLim database (http://www.pragtic.com/experiments.php). Their results under multiaxial loading at the fatigue limits are quite inappropriate, but these two methods are the most often implemented criteria in this area and are well known even to people who are interested in fatigue but know only a little of the impact of the multiaxial loading.

The openness of the PragTic source code to more partners oriented basically on the research itself should change this practice. The implementation centre stays in Evektor, but any partner will have an ability to check the implementation as well as to modify it in his search for the right solution. The extent of the work related to the research and to the verification of existing methods is quite large in WP2-WP6. But this is the only way in the search for a unique conclusion concerning capabilities of different solution types. The same relates to the ability to share the FEA models which are the basis for any fatigue calculation – but more on this point is written in Sec. 1.2.7.

If we pursue this way, the necessary first step in the coordination of further development of PragTic is introduction of all partners willing to work with PragTic's source code. PragTic will be used within the most of the other workpackages for analysis of experimental data. A great part of the new or older methods that will be evaluated during the research will be implemented into it. This means that the participants have to understand how to work with it, how its inner structure looks and what can be done in which way. Although the most of the core implementations is expected to be done in Evektor, it is very important for any learned user / programmer to have an opportunity to modify the parts of the source code in order to test different versions of examined fatigue criteria.

This work starts first by the users studying the control over PragTic, which will be also explained at the first join meeting. During the first half of the year the actualized version of the Help for PragTic has to be finished, together with a set of examples that can help the users in the orientation within PragTic's interface. The second common meeting will be used also for introduction into the source code of PragTic, the common procedures in the work with data blocks, etc. The effort will be spend so that the users were able to orient themselves within the source code of PragTic, know where to look when they need to change some parts of code, were able to do the change itself and check the behaviour of the program afterwards.

PragTic has up to now a very specific import procedure allowing the import of solid meshes of arbitrary FE-solver, but it is too slow for the number of expected fatigue analyses necessary in this project. We therefore expect here to define proper transfer formats between PragTic and ANSYS (CTU, IPM, SV, TCD), NASTRAN (BUT, EVE), ABAQUS (CTU, IPM, MERL, UPAR), ProEngineer (TCD, VCA), COSMOS (SV) and PAM-CRASH (VCA). Great emphasis will be placed on improvement of work with shell topologies, which are very common in aircraft design.

1.2.2 WP2 - WHY TO WORK WITH THE NOTCH EFFECT?

Industrial components and structures almost always fail from areas of stress concentration, i.e. regions on the component where the stress is high, but localised, characterised by a gradient of decreasing stress. It is well known that the estimation of the effect of this high-stress region is difficult; various different approaches exist but none has emerged as a universal solution.

This is true whether the prediction of life (N) is based on elastic stress (S) or elastic/plastic strain (e). **The use of S-N curves is prioritised within this project over Manson-Coffin (e-N) curves, which constitute the basis for a parallel way of the solution. Our priority set to S-N solution was chosen, because it allows much faster and convenient engineering solution, avoiding the complications of elastic-plastic FEA.** Due to the not wholly rightful use of Neuber-like methods solution and from it arising necessity of elastic-plastic FEA modelling, the e-N curve based solution is usable only for simpler load histories as e.g. with constant amplitude loading throughout the whole life of the structure evaluated. Although the S-N solution is prioritised in the plans for PragTicA consortium research, the analyses using e-N curves will be also done for comparative purposes, because of many supporters of the e-N solution that would otherwise rightfully point out that the comparison is incomplete.

Stress-based notch approaches normally involve some parameter, which refers to the size of the highly-stressed region or to the magnitude of the stress gradient. Today the coverage of the notch effect in PragTic is insufficient. Several methods based on the relative stress gradient similar to FemFat solution are currently tested for a uniaxial solution. The same insufficiency is nevertheless valid also for the most of the commercial software – MSC.Fatigue or WinLife ask the user to set manually the notch factor for each critical locality. On the other hand, the method implemented e.g. in FemFat is better automated, but we are lacking any substantial and thorough verification of its quality. Thus e.g. the introduction of FemFat v.4.6 changed significantly the way of the notch effect evaluation in comparison to the previous FemFat version, the change nevertheless has neither been fully documented as regards the implementation details nor has been reported about differences in prediction quality of both methods.

The experimental programme realized within WP2 of PragTicA project should involve not only the notch effect itself but also its interaction **with mean stress effect**. This means that the testing will comprehend also load cases of repeated load. **The experience gained during the build-up of FatLim database lead us to the conclusion that the most of the multiaxial criteria fail more often due to improper implementation of the mean stress effect than due to multiaxial loading.** Because the extension of results in the WP2 (notch effect) is planned, the inclusion and coverage of the mean stress effect within the notch effect is necessary to be verified also within this group of limited scope (no multiaxial external loading – this extension is planned to be done in WP3).

The understanding and proper simulation of the notch effect within the fatigue analysis of the complexly shaped parts has a key role in any evaluation of aircraft structures. As an example we can mention an increase of the number of milled complex parts used in the new VUT100 Cobra or EV-55 Outback aircrafts developed in Evektor. The milling is a fast technological operation with a very good potential to uncover any defects related to the manufacturing. It is therefore prioritised over the common assembly of riveted shaped sheets, which is more prone to human induced errors and necessitates more human labour as well.

1.2.3 WP3 - WHY IS THE MULTIAXIAL LOADING SO IMPORTANT?

Multiaxial fatigue loading induces in the structural components multiaxial local load states, where the individual components of the stress or strain tensors in general develop non-proportionally. Fatigue evaluation of structural components has become a standard process in the design of both civil and mechanical structures. However, multiaxial fatigue continues to be largely the domain of a limited number of specialists. In order to analyse structural components subjected to multiaxial loading, the stress state is generally reduced to an equivalent uniaxial stress state. It is worth recalling that considering an equivalent uniaxial stress state permits a fatigue evaluation based on uniaxial fatigue test parameters and, hence, complex and expensive multiaxial fatigue experimental tests can be avoided, but it often implies simplifying assumptions which might not be valid for the specific load sequence or structures to be examined. The use of uniaxial solution and its results in comparison to the usage of multiaxial methods has to be carefully documented, because it is very often used in the engineering practice but the rightness of such a solution is questionable, while even an inclination either to conservative or non-conservative prediction is generally unknown.

Several criteria have been proposed during the last decades to predict whether fatigue failure under multiaxial loading may occur or not. As far as the high-cycle fatigue regime is concerned, these criteria are based on different approaches including: empirical formulae, stress invariant-based criteria, stress average-based criteria, critical plane approach. On the other hand, for the low-cycle fatigue regime, strain-based counterparts have been proposed as well as energy-based criteria.

According to the critical plane approach, fatigue behaviour under multiaxial loading is analysed in two steps. Firstly, the critical plane (defined as the plane of maximum damage) is theoretically determined by maximising a combination of the amplitudes and/or maximum values of some stress components. Secondly, the fatigue failure assessment is carried out by employing some stress components acting on the critical plane deduced in the first step. As has been shown by Brown and Mille, fatigue process can be distinguished in two stages: fatigue crack nucleation (Stage I) and fatigue crack growth (Stage II). Such stages are characterised by different crack plane orientations and crack growth modes (Mode I or

Mode II/III). Hence, the critical plane approaches differentiate depending on which stage is considered in defining the critical plane orientation. Note that critical plane models should be able to predict both the fatigue life and the dominant failure plane(s).

As mentioned above multiaxial loading induces multiaxial stress/strain states, where the individual components of **the stress/strain tensor in general develop non-proportionally. This is the main reason, why under variable amplitude loading, common rain-flow decomposition used for conversion of the continuous load history for load cycles separation fails.** The most often used solution how to get over this obstacle is to perform the rain-flow analysis of some specific load component only, but no clear and persuasive proof of its functionality was shown up to now. We therefore want to check also another approach proposed by Prof. Stefanov (who joins our consortium within the staff at the CTU) with a revolutionary idea of integration of damage differentials without forming any cycles. The method was repeatedly published in the nineties of the 20th century but up to now no large scale testing of its functionality has been done. PragTicA project with its systematic check of existing methods on available experimental data will be the first large-scale test of this method. The method is certainly worth testing because of its unique way of solution, which no other method currently uses.

WP2 is focused on the notch effect on fatigue life. The solution is there looked for under an assumption of uniaxial external loading. The notch effect use in conjunction with elastic S-N curves is preferred in our point of view over common elastic-plastic solution based on e-N curves. The same postulate is valid also in the multiaxial loading domain in WP3, but the situation is nevertheless even more complicated by the multiaxiality. No tool for a conversion of elastic FE-results to elastic-plastic as it is often used in uniaxial analysis (Neuber, Glinka,…) is commonly accepted within multiaxial analyses and thus **the dependency on the e-N curve leads to the only way of solution – fully elastic-plastic FEA. In such a case, any quick attainability of fatigue results under a more complex loading is real only for very short load histories, constant amplitude loading or under the acceptance of very drastic shortening of the load history. We would like to take the best solutions evaluated within WP2 and extend them to WP3.** We know that FemFat uses its own solution within the S-N concept as well, but any its more extensive public verification is missing. We would like to compare it with other solutions, the final most successful PragTic S-N and e-N methods.

The multiaxial solution is already firmly based in PragTic – see e.g. some of its results in the open FatLim database (http://www.pragtic.com/experiments.php). The current solution is nevertheless focused above all to loading around the fatigue limit, i.e. to purely high-cycle fatigue calculations. The works on limited lifetime solution in this category have already started, but have to be substantially extended in both the S-N and e-N parts of the solution. A substantial relationship to WP2 is expected, while the combination of both effects studied in these two WP (notch and multiaxiality effects) is absolutely necessary for any industrial practice.

Multiaxial load state is intrinsic to many industrial applications. It concerns the contact fatigue, load state around rivets, load state on the crack tip, etc. De facto, any notched specimen has a multiaxial local load state in the notch itself even if the external loading is uniaxial. The understanding to this complex phenomenon and the question, when the simpler uniaxial methods can be used, is of paramount importance to any successful structural design.

1.2.4 WP4 - How to ensure that the welds will not fail?

The engineering solution of fatigue in welds is usually based on Eurocode 3 or BS7608 standards in commercial fatigue applications. Welds are a real complication in the computation – they induce residual stresses, non-homogeneity and substantially increase probability of improper technological operations. The multiple of different effects joint whenever they are placed anywhere on a real structure greatly complicates recognition of mentioned partial impacts. Therefore, there is a lot of space, where to continue in the research.

There is no solution currently implemented in PragTic. Our visions expect implementation of BS7608 and Eurocode 3 first. We want to compare implementations of these two standards in different fatigue solvers, because we assume that the results could differ. Thanks to its origin, Eurocode 3 and BS7608 standards are too conservative for assessment of high strength structures. There is no category that would include e.g. AISI 4130 steel, which will be tested in the experimental section of PragTicA, unless the user accepts significant reduction of its strength and durability values related to the use of S-N curves of common structural steels. **The adaptation of the standards for higher strength steels used in aircraft industry thus allows significant gain in the performance of these steels.**

Later a focus on the solution based on internal forces as proposed by Pingsha Dong (implemented in a specific way in Verity module of Fe-Safe) should follow. **The concept is based on the fact that the force flow through the structure is quite well covered even in cases where the mesh quality does not allow correct evaluation of strains and stresses. This is a great advantage in engineering practice of FE-models preparation.** Our goal here is related to introduction of the nodal force concept to PragTic and its testing with various computational methods. **In conjunction with spot welds, its implementation is a step towards WP5, where an analogous concept will be evaluated on riveted structures.** Here in WP4 it nevertheless concerns a large amount of work dedicated to study of force flow through welded structures and its appropriate way of FE-modelling.

The theory of critical distances (TCD), elaboration and testing of which is planned in WP2 and WP3, has already been tested also in this category. Its more extensive testing would be desirable. Using hot spot approach will be tested and adapted for condition of thin wall welded structure made from high steel. A mesh density and quality of FEM models will be monitored in practical examples of fatigue assessment of real structures and the influence will be compare for each of tested method of fatigue evaluation.

The most common welded structures designed in Evektor are related to undercarriage, engine bed and control system, which clearly belong to very important parts in the aircraft. There is some potential hidden in the expectation that spot welds could be used in some parts of the aircraft structures. In comparison to the riveting, the spot welding does not involve any extra weight (rivets) added to the structures and the potential of joint failure detection is higher, because the critical locality stays bare and clearly visible. The aluminium, which is a traditional material in aerospace manufacturing thanks to its low density, is nevertheless a bit difficult to spot welding due to its high thermal conductivity, low melting range and propensity to form oxide surface film. We thus do not want to evaluate the potential itself, but we would like to concentrate on the task of the load flow and possibilities of fatigue prediction.

1.2.5 WP5 - HOW TO PREVENT RIVETS "GONE IN THE WIND"?

If the fatigue solution in welds is complicated and prone to the appearance of unexpected effects, the problem of riveted structures is even more complicated. They are predisposed to problems induced by non-perfect technological operations. The critical failure location is usually hidden under the rivet itself and at the mating surfaces of the sheets to be joined, which means that the crack is quite long once it can be detected by visual or other NDT means. **The fatigue solution often concentrates on prevention of fatigue problem appearance (different technological operations inducing compressive loads at the holes, etc.) substantiated by tests.** An analytical solution describing peak stresses at the rivet hole based on stress concentration and secondary bending stresses is available. However, this solution still lacks the influence of the complex internal stress distribution caused by the riveting process.

Within this project at first improvements should be made of available (analytical) solutions (FATEC, DUT), which will then be extended to and included in FE applications (EVE, BUT). EVE, BUT would like to test the possibility of extension of the nodal internal forces concept in order to describe the part of the structure life up to initiation of an engineering crack. This part of lifetime is necessary above all for all airplanes based on the concept of safe-life, which can be often found by smaller and medium-size aircraft manufacturers.

The concept realized within EVE-BUT tandem is based on the requirements necessary for any aircraft designer. EVE in its design effort searches for a proper way for counting in the rivet flexibility so that large models comprising of the shells (skin of the airframe) and bars (members, stiffeners, stringers and potentially rivets) were realizable in this simplified form with no precise riveting modelling, while preserving the overall elastic characteristics of the airframe. **The joint member would be simulated either by a direct linkage of the points on joined sheets or by a dedicated element. There is at least one further requirement – the rivets has to be placed to an arbitrary place on the FE-model with no specific requirements on the FE-mesh adjacent to it – they need not to start and end at nodes of the shell elements.** This postulate means that the automation of the mesh generation could be used up to maximum and the rivet entities would be placed only after the meshing of the shell structures.

Once this FEA solution is optimised then a clear similarity to WP4 can be seen. Both solutions do not model the stress or strain fields around the joint in detail or correctly at all. The force flow through the joint calculated by the FEA should nevertheless correspond to the reality as much as possible.

In comparison to spot welded joints, riveting has more process variables – this is not only the thickness of the sheets, but also the type of rivets, their dimension, use of a sealant, quality of the production, force induced, etc. This is the reason why the amount of man-months dedicated to this solution was set in such a way as can be seen in the WP Task 5.1. The solution is planned to be simultaneously implemented and tested in PragTic with the major goal of fitting the experimental results to FEA and PragTic results. **It is clear nevertheless, that only limited number of rivet and sheets configurations (as being experimented) will be covered within the PragTicA project.**

1.2.6 WP6 - WHY THE COMMERCE AVOIDS SOLUTION IN COMPOSITES?

The use of composite materials has seen considerable growth in many industry sectors in latter part of the 20th century and this growth has continued into the 21st century. The interest in composite materials is driven both by performance factors and environmental factors. The material's higher specific strength and stiffness has catapulted the use of these materials into the civilian aerospace market. These same properties along with energy absorption have made vast improvements to the performance of many sports including Grand Prix racing, skiing, golf and tennis. Composite materials are perhaps the only material of choice in certain highly corrosive environments such as the petrochemical industry. These materials are also now being selected for environmental reasons because their low specific weight leads to fuel savings in the transport industry, allows for the design of large wind-turbine blades and can be used in construction projects for longer product lives.

However, despite this growth in the demand and use for composite materials, their long term properties when exposed to a combination of in-service fatigue loads and environments are still not well characterised. In addition many of the design methods are based on static properties and failure criteria. The effect of exposure to heat, moisture, solvents, acids, ozone, hydrocarbons, in addition to the fatigue loads, etc., may degrade the material's stiffness and strength leading to cracks and ultimately failure of the materials to meet its purpose. **The lack of long term data or of a robust fatigue methodology that will predict progressive damage and the residual properties and future life are two of the major issues still hindering their wider use or leading to over design.**

However, with the increase of composites usage in fatigue dominant structures such as fan baldes, helicopter rotor sytems, wind-turbines, pressurised commercial jets – a fatigue analysis and design methodology is vital to the continued specification of these materials.

Ability to reliably predict the fatigue life and damage tolerance of composite structures subjected to dynamic load is of paramount importance. Development of standard/general tools for predicting fatigue of composite materials is very complex, mainly because a number of different damage mechanisms may be present at different locations. The two main approaches employed for predicting fatigue of composites can be classified as either mechanistic or phenomenological. The mechanistic approach uses damage tolerance methods to discretely model the initiation and growth of damage. The phenomenological approach uses the safe life principles to define fatigue life in terms of macroscopically measured properties. It is proposed that both approaches be implemented into the Pragtic.

1.2.7 WP7 - HOW TO DO THAT ALL AND NOT TO GET LOST?

The list of PragTicA participants is quite long. As regards the individual WPs, the most of them are based on a collaboration of 5-6 different organizations. Because the project involves relatively extensive scope of programming work and we should ensure that the new ideas born in various WPs are realizable within PragTic or any other programming tool, the coordination of the most of WPs was set to two person – research coordinator and SW implementation coordinator. More on this point is given in Sec. **Chyba! Nenalezen zdroj odkazů.**.

There is a lot of work done in comparison of different SW packages. **Maximum emphasis has to be placed on systematisation of the experimental data processing, FEA-simulations, fatigue simulations, ways of an evaluation of resulting data.** This is the necessary condition if the mutual comparison of different methods and approaches on any larger data set should occur. This should be in large contrast to contemporary research practice, where the experimental data sets are either quite small or they are not published completely. We see this problem as the main reason why there are so many different types of solutions available but no clear mutual verification is disposable. **The experience gained throughout the development of FatLim on-line Internet database (http://www.pragtic.com/experiments.php) shows, that this unsatisfactory state of the art can be surmounted.**

The most of the results should be published as widely as possible in order to provide a better support for all those small and medium sized companies that would like to use any fatigue software. The common dissemination policy is created and realized in WP8 (see Sec. 1.2.8 here) with a great emphasis on the open Internet solution, which should simultaneously serve as the collective interface for all project partners (see Sec. **Chyba! Nenalezen zdroj odkazů.**).

During the work a great accent should be given to gathering the information already available in different previous research works and papers. These data will be collected and included into our test database, which will serve as the main input for the verification of the various tested software.

Very important place in our plans is given to the building of FEA-models simulating the experimental conditions. The great advantage of sharing those complex FEA-models and thus sparing significant effort for the most of the participants should be highlighted.

1.2.8 WP8 - DOES EVERYBODY KNOW ABOUT IT?

The problem of present situation in commercial software tools has been already mentioned. It is not a specific problem related to fatigue FEA post-processors, it is much more general (e.g. in the FEA category itself). People tend to believe that the computer and the software they have can solve their problem and everything they have to do is to insert the model somehow and let the computation be run.

But not only the human factor can have devastating effect on the quality of the prediction as it is by FEA (e.g. wrongly built and loaded model). If the user uses wrong computational fatigue model, be it due to insufficient documentation that would otherwise tell him not to use it or due to inaccessibility of another solution, the results can be completely misleading. If there is no unifying physical background describing the fatigue damaging phenomenon in whole its scope, how the user can even expect that he can get right results? Has he seen results of the method under similar specific load condition, boundary conditions or material? Usually this is not the case. People WANT to rely on this mere fiction. There is the expectation hidden that if such an analysis has not been done by the software producer himself, the researcher who had invented this method or his followers did it.

We see that the responsibility for the result validity is subsequently transmitted from the fatigue analyst (who, had not been there the fatigue solver, could maybe do that another way, with more conservatism involved) to the software producer (who anyway disclaims any responsibility for the losses incurred by the use of his software) and from the software producer further transmitted to the researcher / inventor (who in fact has no responsibility – he provided only the idea, had limited funding and time so he tested his new method on data he had).

The fatigue analyst is responsible for his work (but would like to shift it to the software), the software producer is responsible for his work (but denies it) and the researcher is not responsible at all. So, who is the one to be blamed here? If anything happens the fatigue analyst will be blamed because he was so stupid to use the software, which has not been verified for such a use. And no matter how much the bosses pressed him that the software has to be used instead of fatigue experiments and no matter how the software resellers claimed the software is marvellous and easy to be used.

If the concept of virtual design should be effectively used anytime in the future, the overall situation has to be substantially changed. Our prime idea is that there should be a public body, which would thoroughly evaluate the situation in the development of new methods or on the market of the fatigue solvers. Its function would be dyadic:

- to select interesting new methods for large scale testing on up to date retrieved experimental data;
- to check any new calculation method that is implemented to commercially marketed software.

Nowadays, constitution of such a documentation office and its run is an expensive idea. The PragTicA project nevertheless would like to start the discussion about its establishment at least.

The worst in the current situation is that the user does not have any measure how to relate the load and specimens conditions to the quality of prediction results. The extent of the testing conditions of the most contemporary fatigue criteria is too limited even for an experienced researcher, not only for a common engineer who has limited means and time to search for it.

By this project, we hope to build a nucleus of a larger movement that could finally either persuade the SW manufacturer that the documentation going with their products has to be much thorough or stimulate the establishment of the documentation office common to all fatigue analysts and software. This is the only way, how the potential users could be warned that the products they use could give results, which can be misleading under particular circumstances.

The way to attain this goal is based on experience gained during the establishment of the FatLim database (http://www.pragtic.com/experiments.php). The Internet provides the right medium, which is much more interactive than any hardcopy or journal publication. Note, how rarely an errata is printed in International Journal of Fatigue. The experience with FatLim shows that a big part of the papers contains some factual errors, which are incurred by typesetting, wrong corrections by the authors, benevolent adoption of experimental data from other papers, etc. But anything what is printed there is like a gravestone – the waiting time for any publication is very long and people who find the wrong paper later have not any notion that this it is wrong and revised in some later number of the journal.

Internet is not as dead - what is printed there is actual and can be anytime corrected – in fact much more emphasis should be placed on a documentation of the corrections so that the users knew that something like that happened. **The basic concept would be adapted from FatLim and further extended.** There has to be a set of databases. The lowest level is the level of references to individual papers. The next level is the database describing material values. Each material there is related to a referenced paper. The next level is the set of databases describing set of experiments with similar conditions – it relates to some specific material, way of loading, joint conditions and some specific reference. Then there is the database set referring to individual load conditions, boundary conditions, etc. – i.e. to one specific test from a set of tests to which it relates. And finally there is the set of fatigue prediction results – they relate to individual calculation methods and to individual fatigue tests.

The database set can be created as quite open to new users and not only to PragTicA participants. Any user who adds a new item becomes its manager – he has to take care of it. If he checks some data in database and finds it correct he can sign it. The signs confirm validity of the data item and can be perceived as a mark of quality. If somebody disagrees with an item in the database, he can change it (if he is its manager) or can publicly propose its modification to the manager. The manager can either accept it or reject it within the firmly set period. If he does not do anything, his manager privilege is passed to the proposer who confirms the proposed changes.

This is only a brief sketch how to ensure that the data experimented and collected during the PragTicA project can be used and published with the largest possible impact and ability to intrigue people who should reflect them. There is some time necessary to get the information on the database sets existence to the engineer and research public but our joined effort, papers in scientific and engineering journals, holding of the annual PragTic Users' Conference and of the multiple of workshops on the computational fatigue should manage it. **Moreover, the interactive concept of data insertion open to any new data input done by various logged users provides the hope that all the retrieved data will be preserved and even multiplied after the end of PragTicA.**

1.3 S/T METHODOLOGY AND ASSOCIATED WORK PLAN

The very first activity that starts the consortium motion is related to study of PragTic done in WP1. PragTic will be used very extensively within the solution of WP2-WP6. The participants wish to have an access to its source code and its provision is a necessary requirement for successful run of the project. The study of PragTic thus comprises of both use of it through its interface and ability to understand different parts of its source code. In fact, since the most of the partners will use researchers for their input to the source code and not the professional programmers, the length of the period allocated for WP1 could be substantially higher.

Evektor allocated even higher number of man-months. It has to ensure completion and actualisation of the Help system to PragTic, precise description of individual functions and procedures and preparation of example cases that could lead partners (or other users) through the learning period. Moreover, it is necessary to complete the automation of FEA-data input and output from PragTic back to FEA (for graphical post-processing). The up-to-date solution of data import to PragTic would be too slow for the number of analyses prepared within WP2-WP6.

The WP2-WP6 work packages differ in their focus on various fatigue problems (WP2~notches, WP3~multiaxial loading, WP4~welds, WP5~rivets, WP6~composites). They all start in the 3rd month of the PragTicA project course and the evaluation of the research ends at the end of the project in 48th month. They have a very similar structure. The rest of the first year is spend on the compilation analysis of the topic, preparation of experiments, decision which calculation methods should be primarily implemented to PragTic.

The second and third years are experimental. The only exception is WP3~multiaxial where the capacity problems, which concern the sole testing facility able to put on a non-proportional multiaxial loading, force the consortium to prolong the testing from Month 6 to Month 42 (i.e. to 3 years altogether). But not only the experimental part will be realized within those 2 years. The research itself, implementations, the first verification of implemented methods with experimental data or search for experimental data available elsewhere have to continue even in this period. The decision taken in the end of the first year concerns in detail only the 2nd year (the 1st year of the testing). The analysis of new knowledge and of results of the experiments done up to now permits re-evaluation and setting of refined experimental program for the 3rd year. The fourth year is taken as a reserve if anything in the experimental program went wrong, but its main focus should be placed on analysis of all retrieved data, evaluation of all the results obtained either with the commercial fatigue solvers or with PragTic, search for optimum solutions in all categories and preparation of common recommendations concerning the fatigue topics and FEA-results post-processing.

A very important place in our plans is related to the dissemination of not only our conclusions concerning fatigue methods but also of the setup of experiments and prediction results. This is the only way how to preserve the applicability of results of our project to maximum number of interested persons. The set of databases with the structure as described in Sec. 1.2.8 will be prepared. Its items, structure and relations will be prepared in the 1st year and the main framework will be established in the year 2. The rest of the time they should serve to its defined purpose – i.e. presentation of PragTicA results, which will be subsequently input there, and of any further data that other users add to this living system.