VISUALISATION OF SURFACE DEFECTS IN SHEET METAL PANELS

T. Dutton
Ove Arup & Partners, Coventry, UK

E. Pask
Ove Arup & Partners, London, UK

Defects
Forming
Quality
Panel
Surface
Visualisation

ABSTRACT

Application of implicit and explicit solvers has proven the usefulness of simulation to predict splits and wrinkles. The challenge now lies in extending the use of simulation to analyse aspects of panel quality. Chief amongst these are defects due to small deviations from the as-designed surface. These defects can be seen around formed areas within largely flat panels. The defects can be obvious to the naked eye even when less than 30μm deep; simulation involves the full sequence of forming operations including springback. While these calculations can predict displacements, they cannot reveal the visual impact of the defect. This paper describes a method to visualise surface defects using a combination of LS-DYNA and LS-NIKE3D together with the ray-tracing code RADIANCE. Results from initial investigations are presented.

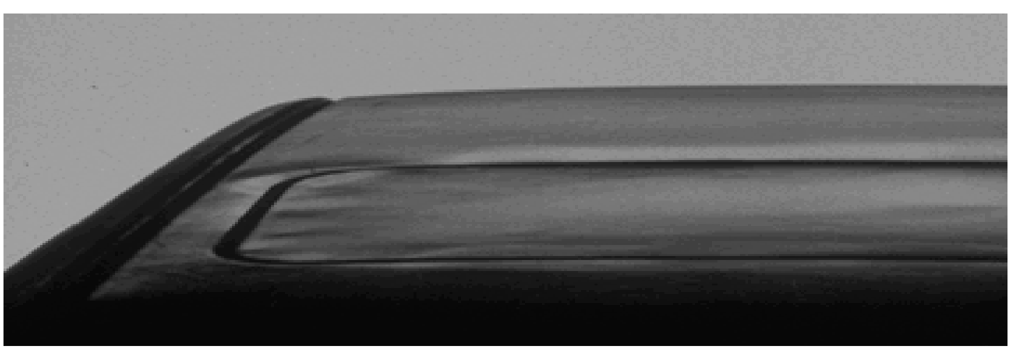
INTRODUCTION

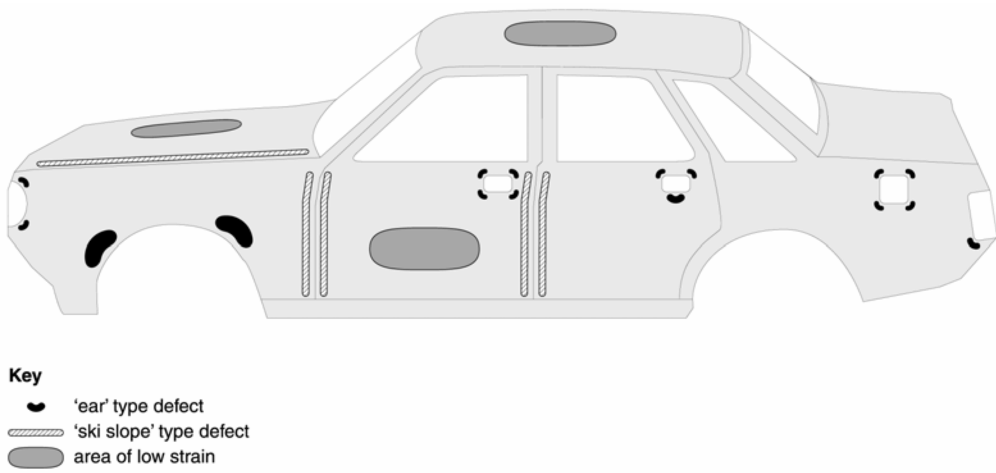
Background

Simulation of forming sheet metal panels has made great advances in recent years. It is now commonplace to simulate draw operations using a variety of computer codes including explicit and implicit time integration techniques or one step solvers. These methods have proved useful for predicting serious failures, such as splits or wrinkles, in the first form panel. Techniques are improving for the prediction of springback after forming, normally using an implicit solution method. In the automotive industry in particular, attention is now turning to other aspects of panel quality and one area of interest is the issue of surface defects.

Surface Defects

Surface defects in pressed sheet metal panels can be defined as geometrical deviations from the design surface. Defects have amplitude from 0.5mm down to 30μm or less but have a relatively large wavelength, usually in the range of 50 to 100mm. These deviations occur most often on large, relatively flat panels in the region of strongly deformed areas; examples include defects around the handle aperture in a door outer panel or the sunroof aperture on a roof panel. Figure 1 shows an example of the latter; the distinctive shape of the defect around the corner of the sun roof gives them the name of "teddy bear" or "mouse" ears. Other defects of this kind include areas of low stiffness in the centre of a flat panel (which when severe results in "oil canning"); and the "ski slope" effect on the edge of an outer panel which has been flanged or, especially, joined to an inner by hemming. Typical locations for these different types of defects are shown in Figure 2. After painting, these defects cause unacceptable visible distortions in the panels which are associated with a low quality product. Rework to remove or reduce the defect is an expensive





and time consuming operation.

Aims

In order to gain improved understanding of the causes and to investigate ways to eliminate or at least reduce the effect of a surface defects, it is necessary to devise a visualisation method to reveal its visual impact. The aim of the work described in this paper was to develop a methodology capable of providing:

1. A virtual Green Room to assess panel quality;
2. Visualisation of surface defects resulting from forming and springback simulations;
3. A comparison of the formed part with design.

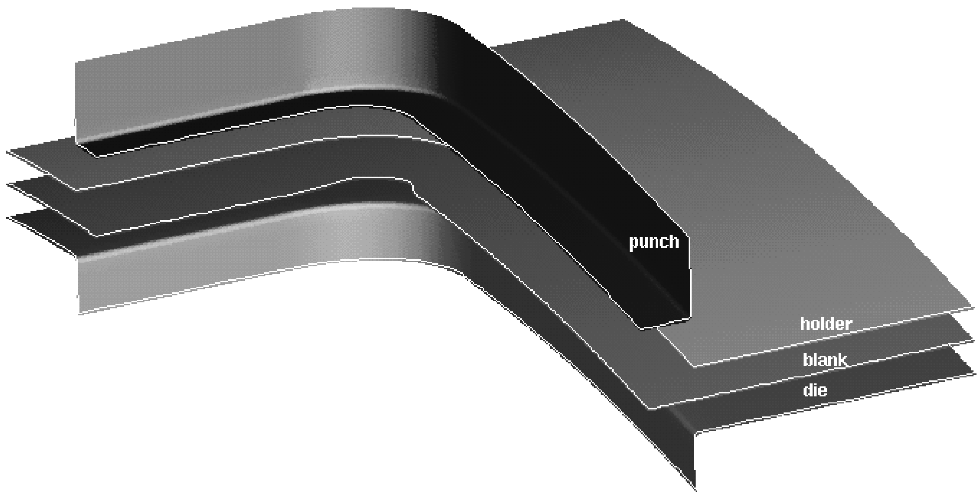
APPROACH

Analysis Method

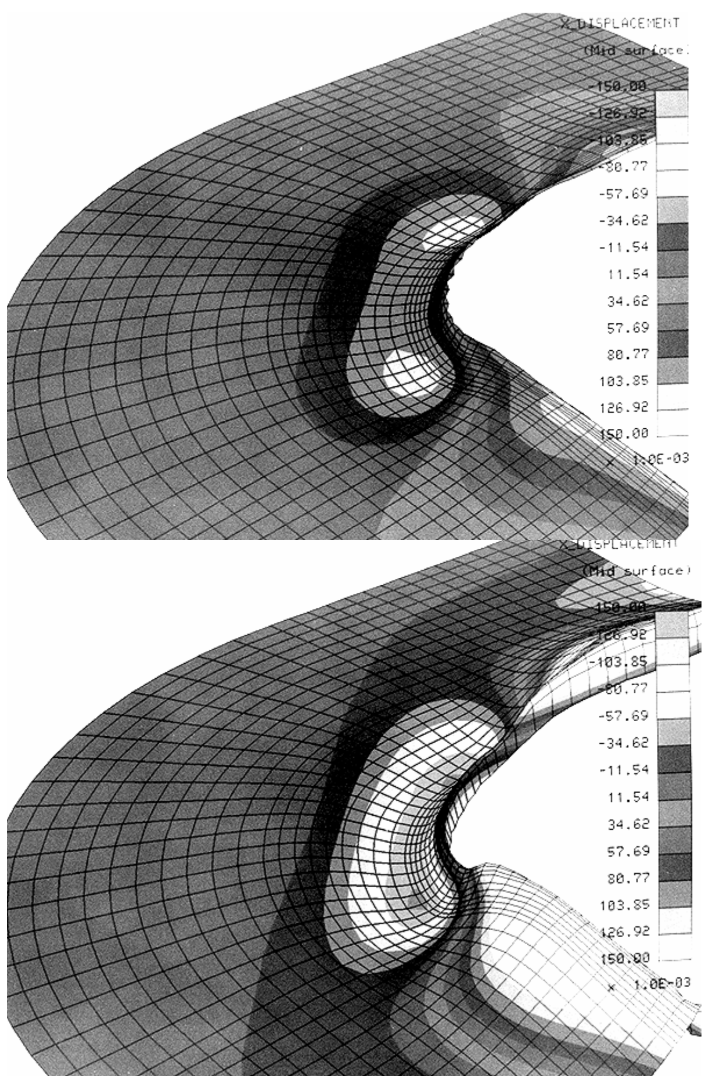
Surface defects are understood to be the result of elastic recovery of non-uniform strain distribution in forming. Neighbouring regions strained by different amounts will have unequal elastic recovery and therefore differing residual stresses. Negative (i.e., compressive) residual stresses may lead to buckling instability in the lower strained region. Such problems are exacerbated with materials prone to greater degrees of springback, e.g., high strength steels due to their higher yield stress, or aluminium due to its lower Young's modulus.

It is possible to simulate the forming process and evaluate the residual stresses, elastic recovery and thus the distortion in the panel. The example presented here is the forming of a roof panel similar to that shown in Figure 1. Only the flanging operation is considered here; the initial strain distribution after the first form operation is ignored as well as any change in stress due to the piercing of the sun roof aperture.

The model, shown in Figure 3, comprises a die, blankholder and flanging punch together with the mild steel blank. Generalised tooling geometry was used. The punch is moved down to form the flange over a 3mm die fillet radius. After forming, the contact to the tools is removed and the blank allowed to recover elastically to simulate springback. The forming operation was simulated using LS-DYNA; springback was also simulated with LS-DYNA (using the dynamic relaxation method) although more recent work has used LS-NIKE3D which is now able to take results from LS-DYNA to define the initial stress condition.



The resulting displacement after springback is shown in Figure 4; vertical displacements are magnified by a factor of 100. The distinctive shape of the teddy bears' ear is predicted with a maximum dip in the surface of approximately 50µm. It should also be noted that a ski slope effect has also been predicted along the straight edge of the sun roof aperture.

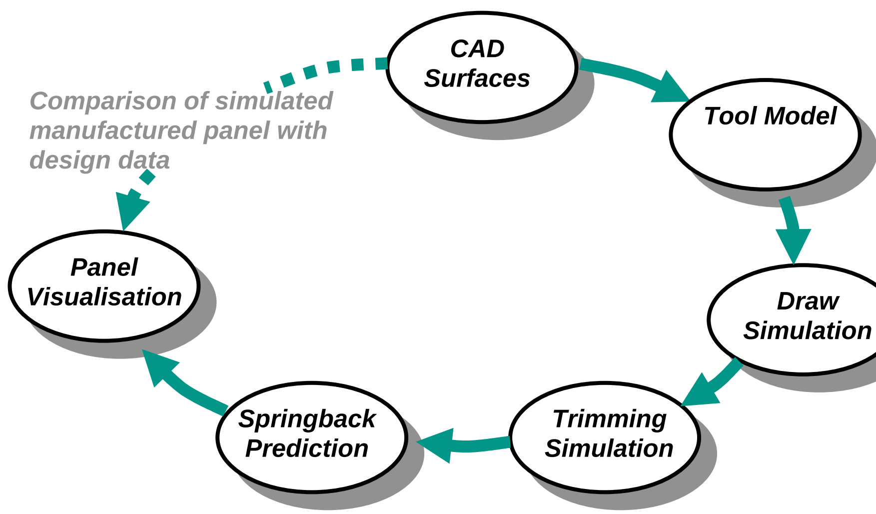


The same model was used to examine the effect of tooling misfit. A gap was introduced between the blankholder and die with a maximum of 0.3mm (plus material thickness) at the die inlet tapering to zero on the outer edge. This was found to dramatically increase the severity of the resulting distortion as shown in Figure 5 with a maximum dip in the region of 125µm predicted. It is believed that the large increase in the size of the defect due to tool misfit could explain much of the variation in quality from batch to batch noted in production.

Visualisation

Method. The analysis method described above has been found to be suitable for the prediction of displacements of the type measured where an "ear" type defect exists. This method, however, is not capable of predicting the visual impact of such a defect. It is well known in practice that a given size of defect can be acceptable on one panel and not on another and that even the chosen paint finish can have an effect on appearance. After examining results from a range of graphics rendering techniques it became clear that the best way to visualise the defect would be to use a photo-chromatically correct ray-tracing method. This approach is felt to be the only way to detect defects as small as 20µm and ensure that defects which are visible to the naked eye will be revealed (while those that are not will not).

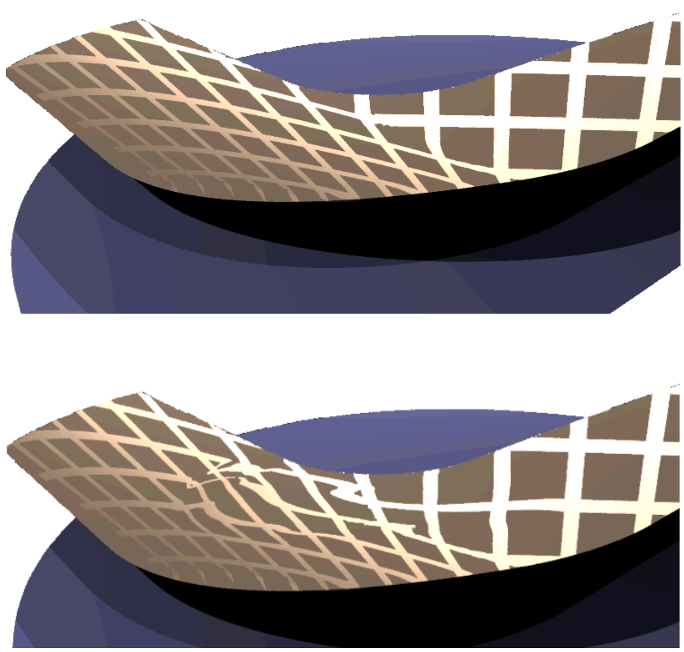
The sequence of calculations is shown in Figure 6. CAD data is used to create a tool model in order to simulate the first form draw operation, followed by trimming and springback; additional operations such as flanging (with subsequent trimming and springback) may also need to be simulated. The output from the final springback calculation is then used as the input to the ray-tracing program to reveal the visual impact of surface defects. The final stage is then to import the original design from the CAD system to compare the manufactured panel with design intent.



Work to date has used the ray-tracing program RADIANCE (Ward, 1996) developed at Lawrence Berkeley Laboratory in California. RADIANCE was developed as a research tool for predicting the distribution of visible radiation in illuminated spaces. It takes as input a three-dimensional geometric model of the physical environment and produces a map of spectral radiance values in a colour image. The technique of ray-tracing follows light backwards from the image plane to the source(s). Because it can produce realistic images from a simple description, RADIANCE has a wide range of applications in graphic arts, lighting design, architecture and computer-aided engineering.

While RADIANCE may not be the easiest ray-tracing program to use it is generally held to be one of the most accurate solutions available and it has effectively no limitations on the geometry to be used. Modifications were made to the LS-DYNA/LS-NIKE post-processor to output displacements in a format to be read directly by RADIANCE. This required output of nodal coordinates together with its normal direction; input to RADIANCE is via the *gensurf* command. Details of the lighting environment and positioning of the object to be examined are handled in the RADIANCE pre-processor. Calculation times vary from several minutes to hours, depending on the complexity of the model and the desired output quality. Results are in the form of digital images (such as Tagged Image Files) and "fly by" sequences can be created as MPEG movies, although this can require several hours on a typical workstation.

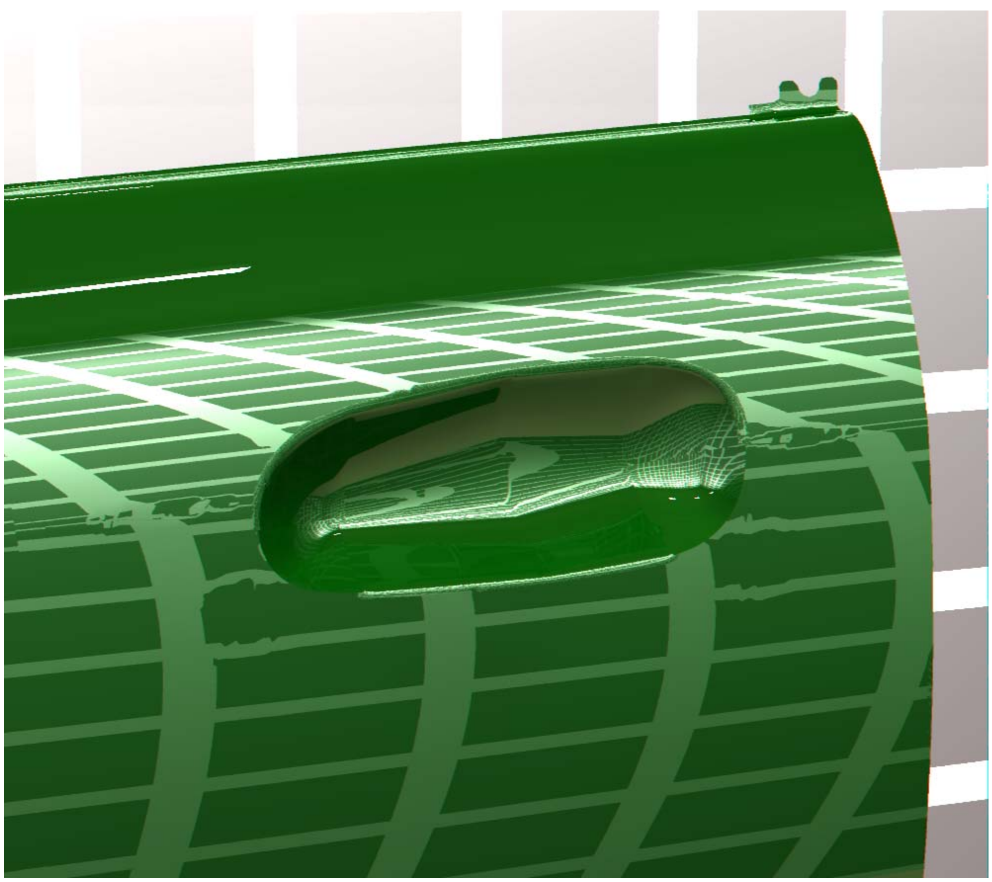
Roof Panel. The results of applying this technique to the roof panel analysis previously described are shown in Figure 7. A segment of the roof around the sunroof aperture has been analysed in RADIANCE. The panel is placed on a table in the centre of a room; an array of vertical and horizontal strip lights has been placed on the walls of the room and the reflections of the lights can be seen on the panel. It is possible to create practically any lighting environment representative of the Green Room set up favoured by the sheet metal stamper; an environment with natural light can also be created. The reflectivity of the panel can also be controlled to simulate the use of highlighting oil.



The upper image in Figure 7 is the die surface which represents a perfect panel; the lower image is the as-formed panel with the "ear" defect clearly visible from the distortion of the reflections. Experiments using a subtraction process within RADIANCE show that the difference in the two surfaces can be highlighted and quantified as part of the analysis but it is felt that the most effective technique is to give the most photo-realistic image possible and allow the human eye to examine the results, just as is done in reality.

Door Outer. The same approach as described above has also been applied to a door outer panel. In this case the defect occurs around the depression formed for the door handle. These defects are smaller and shallower than those occurring around sunroof apertures but are often extremely obvious to the naked eye. A very detailed model of the panel is needed to pick out small defects; in this case 100,000 elements were used. A similar lighting environment to that for the roof panel was used and a typical image from the fly by video sequence is shown in Figure 8. Two defects in the main door outer surface are clearly revealed to the lower left and right of the door handle recess. There is also a discontinuity in the reflected lights across the mid-height of the handle recess; this is due to the reflection of the join between wall and ceiling of the Green Room and is a function of the viewing angle selected. Distortions in the reflections have also been detected on other parts of the panel not shown in Figure 8 which are due to a mismatch where meshes on two adjoining patches meet with poor surface continuity. This has demonstrated that an extremely high quality model is required to obtain accurate results.

This preliminary result has confirmed that visualisation of surface defects at an early stage in the design process will have a number of benefits. Ray-traced images from forming simulations will allow defect severity to be assessed visually allowing key aspects of quality control to be addressed earlier in the design cycle. The severity of defects with different flange or recess geometries can be assessed, and countermeasures such as initial strain condition or tool over crowning can be evaluated.



DISCUSSION

Further Developments

Surface Defects. The work reported above has focussed on visualisation of defects of the type often referred to as “teddy bear ears”. The roof panel example also revealed a “ski slope” type defect along the straight edge but more work is needed to look at this type checking, in particular, how these defects relate to the hemming process. The effect of radius, initial strain condition, material properties and so forth need to be examined.

Areas of low strain in the centre of flat skin panels should also be possible to visualise using similar techniques. In reality, this type of defect is often linked with problems of insufficient panel stiffness revealed in a force vs. displacement test but careful examination of the surface (by a trained eye) generally reveals the existence of a problem of this type.

Assembly Issues. Other than issues relating to individual panel quality, work has also been done to visualise the resulting assembly operations. By modelling both a front and rear door and then experimenting with alignment it is possible to obtain photochromatically correct images of the effect of door gap or door flushing tolerances. This has the potential to visualise the effect of variations not only within individual panels but also those due to the complete assembly process. The results could influence design decisions relating to Geometric Dimensioning & Tolerancing as well as assisting in adopting optimum manufacturing methods.

The full range of variables affecting the final result is considerable; it includes material properties (blank thickness, size, “K” and “n” values, etc.), press variables (tool set up, tonnage, parallelism, etc.), assembly (jigs, spotweld forces, handling, storage, painting, etc.) and even paint shop operations. Some of these variables, such as materials and assembly loads, can be studied using computer simulation. Processes worthy of further investigation include hemming operations and the distortions introduced by poor jig fixture locations. Other variables will require statistical studies of the manufacturing operations themselves. Given the number of potential variables for large assemblies it will be necessary to employ a variation analysis technique to determine the range of possible mismatch. An approach combining variation analysis with a design of experiments approach may be needed to determine the critical parameters.

Improvements to the Technique. The work done to date has revealed that visualisation using ray-tracing has the potential to reveal the visual impact of quality-critical surface defects. Further tests are needed to correlate the technique and experiment with the optimum viewing conditions to ensure that all true defects can be identified and that “defects” due to model quality are avoided. Green Room layout, viewing position and paint finish, including colour and “glossiness” (i.e., contrast) of the panel, must all be assessed.

Aspects of the method need to be investigated further before the application can become widespread. Contact calculations in LS-DYNA are generally based on a penalty factor method which allows a certain amount of penetration of the contacting node into the tool surface. The formed shape does not therefore conform exactly to the tool surface. Although the contacts are not present during the springback calculation it is possible that the small inaccuracies in the forming simulation could be enough to affect the surface defects which we are attempting to identify. An alternative contact algorithm based on a constraint method is also available in LS-DYNA and it may be necessary to use this for future work. The effects of mesh quality and model detail also need to be evaluated.

One other difficulty should be noted, namely the wide variation in the amount of springback observed in practice. As springback relates to the recovery of elastic strain after forming even quite small variations in factors such as material thickness or yield strength can have a marked effect on the amount of springback recorded. Moreover, as the work on the sunroof problem revealed, relatively small tool misalignments can also have a significant effect. This work equally shows that these variations can be included in the simulation and such factors must be understood in order to apply this type of simulation effectively.

The described technique is dependent on high-speed computing. Large numbers of small elements must be used and the full sequence of forming operations must be simulated and the ray-tracing calculations themselves, especially if a video sequence is to be created, are computationally intensive. Nevertheless, the approach clearly has much to offer as manufacturers strive for ever improving quality while at the same time attempting to eliminate prototype tooling. This technique should, when fully developed, allow the vehicle designer to appreciate the impact of the full range of forming and assembly processes on the intended design and guide any changes to ensure the best possible quality is achieved from Job 1.

CONCLUSIONS

1. A combination of implicit and explicit time integration finite element calculations can successfully simulate the displacements associated with surface defects such as “teddy bears' ears”;

2. The visual impact of such simulated defects can be examined using photochromatically correct ray-tracing techniques;

3. The combination of these methods will allow the designer and manufacturing engineer to identify areas of concern earlier in the design process and examine the benefit of design or tool modifications.

ACKNOWLEDGMENTS

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