Boeing 767-400ER Raked Winglet

Project done by:
UBC (CMT) and Boeing Phantom Works

Project funded by:
AFMRL (Processing for Dimensional Control)

Summary:

A sensitivity analysis of the Boeing 767-400ER raked winglet front spar was performed using process modelling (COMPRO) to study the effect of material and process variables on flange spring-in. Model predictions were in good agreement with experimental results and the simulations were used as a basis for design of the production tool. The simulations provided a tool compensation factor for spring-in as well as an understanding of the sensitivity of the spring-in to variations in material and process variables.

References:

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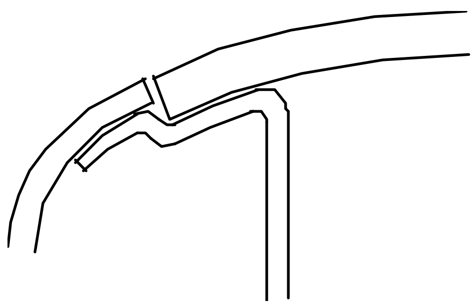
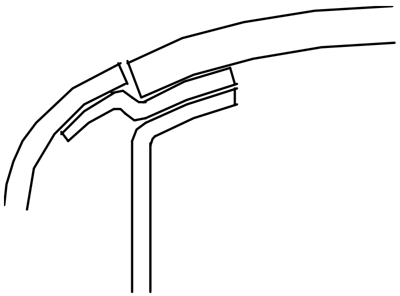
Boeing 767-400ER raked winglet

767-400ER winglet design options



767 Winglet front spar, flange forward design concept.

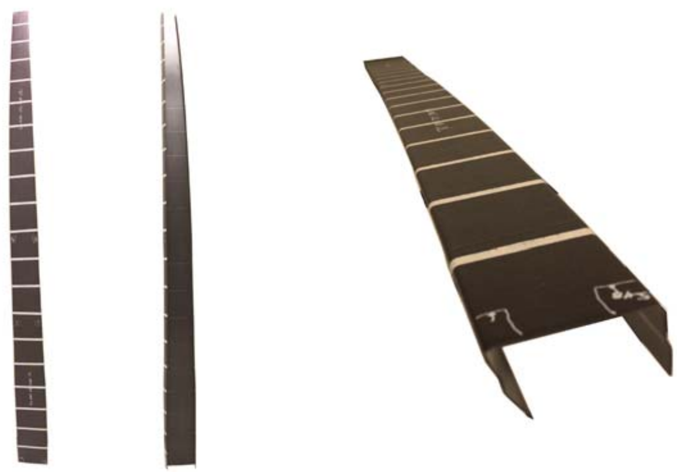


Winglet front spar, flange aft design concept

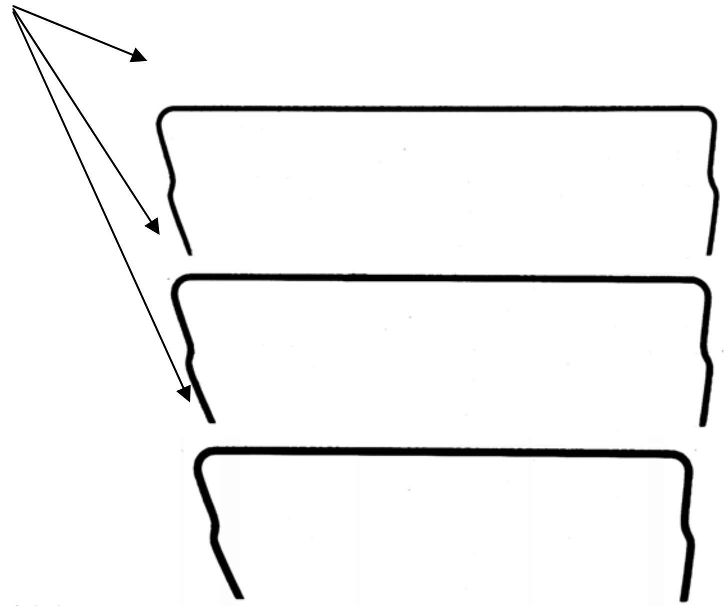
- Flange forward design concept selected for reduced part count and simplicity
- Greater dimensional control challenge due to longer flange

Spar configuration

Flange angle changes along the length of the spar

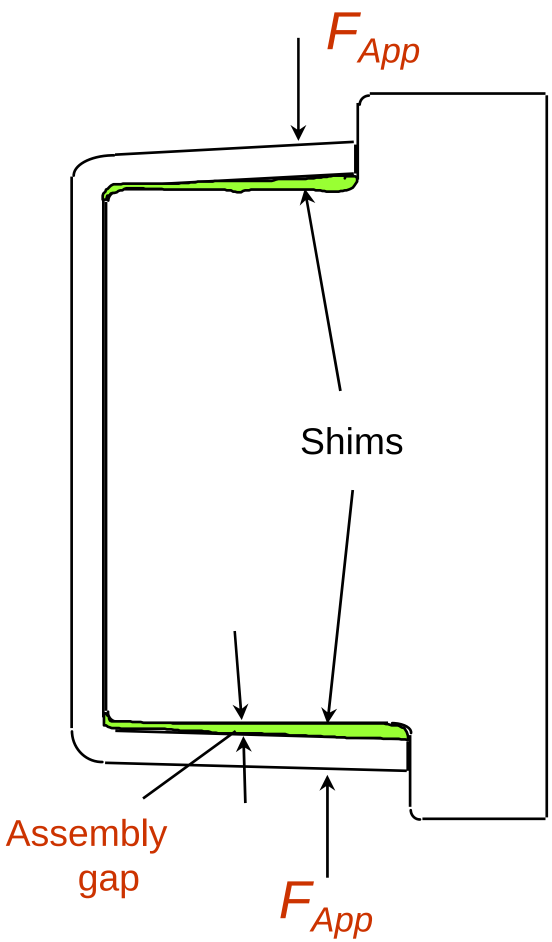


Photographs of the 767-400ER winglet front spar showing locations of data collection (white).



Spar cross sections taken at 6, 24, and 36 inches from root end (top to bottom).

Dimensional control and assembly



Gaps between sub-components are:

- inevitable and variable
- often require force-fit or shim-to-fit
- affect design loads

Conservative design guarantees gaps

- gaps guarantee additional cost

Ideally:

- design tool and part for shim-less assembly
- requires good understanding of cured dimensions

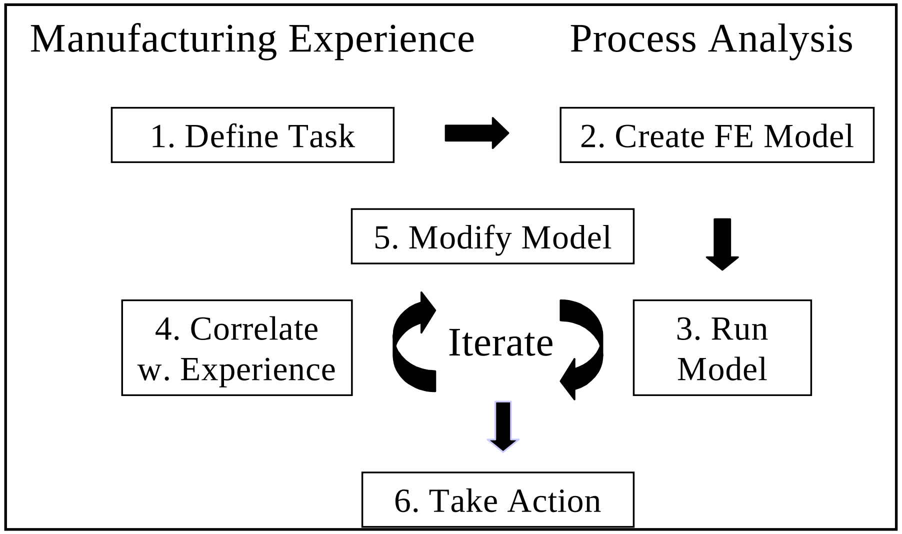
767-400ER raked winglet analysis

- A large sensitivity analysis of the proposed process was performed using design of experiments (virtual experiments)
- Flange spring-in angles were calculated along the length of the spar
- Predicted spring-in angles together with measurements on prototypes served as a basis for the manufacture of the production tool

Flow chart of analysis approach

Goals of process simulations

- Develop understanding of the process
- Identify main drivers for spring-in and warpage
- Verify model predictions with measurements

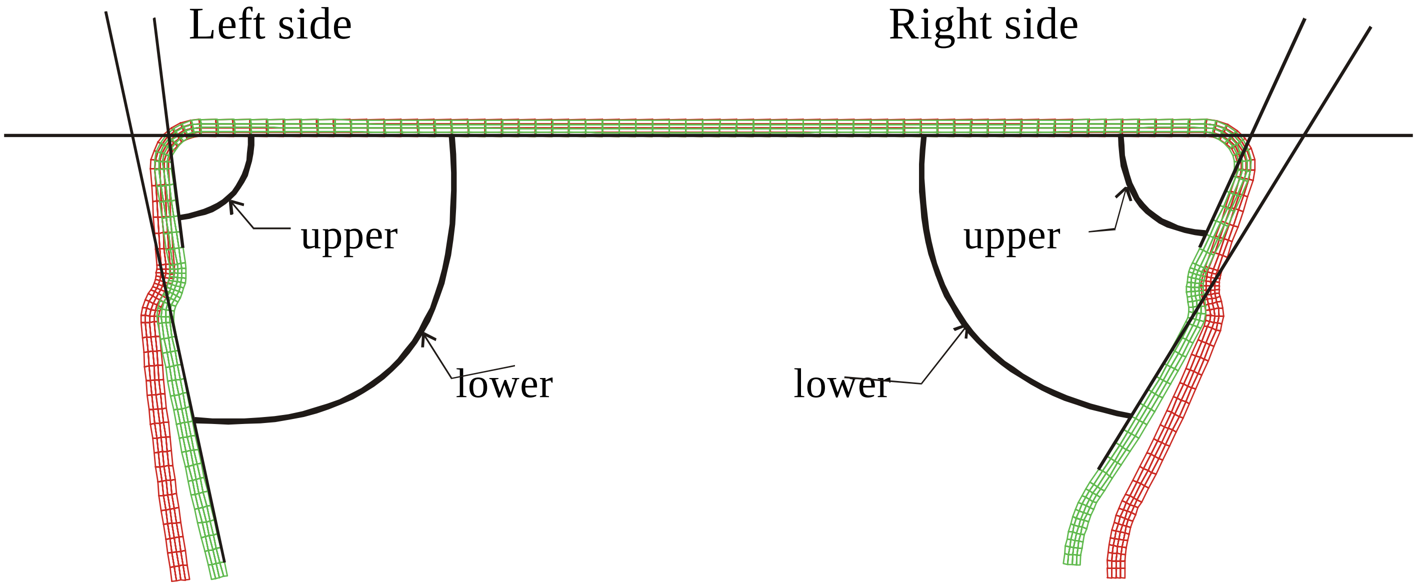


Predicted deformations (COMPRO output)

preliminary analysis

Red = Initial shape

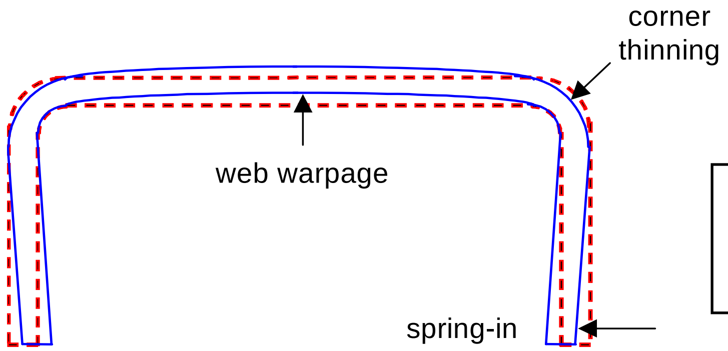
Green = Final shape



Note that mesh deformations are exaggerated in the image above

Preliminary analysis

Preliminary analysis revealed the typical process-induced deformation of a spar cross-section shown schematically below



Red = Initial shape

Blue = Final shape

Predicted corner thinning and web warpage were too small to be of practical importance and focus was placed on flange spring-in

Factors used in numerical DOE

- To develop an understanding of the process and to identify the main drivers for spring-in, a numerical designed experiment was undertaken
- Five process and five material factors were studied in the DOE
- Each factor was set to a low and a high value based on input from the manufacturing engineers

Process factors

- Cross-section (Root, Tip)
- Toggle radius
- Flange length
- Tool thermal mass (solid, hollow core)
- Heat-up rate

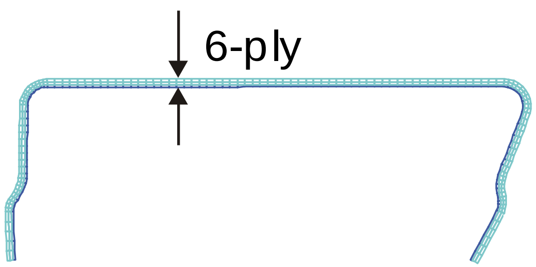
Material factors

- Cure kinetics
- Modulus development
- Resin CTE
- Cure shrinkage
- Resin viscosity

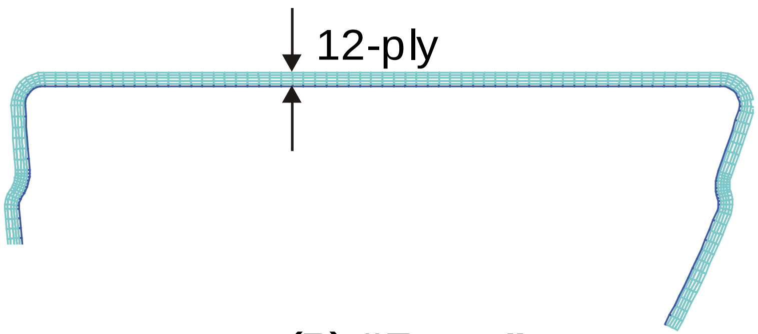
The following slides show examples of low and high values of the process factors

FE meshes of spar cross-sections (part only)

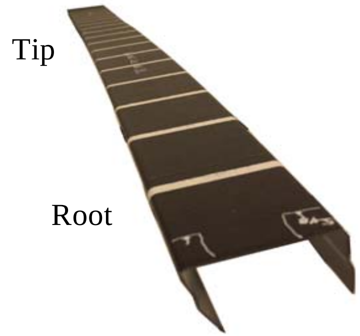
• Generated FE meshed of the tip and root end of the spar, representing the low and high setting of this factor



(A) “Tip”



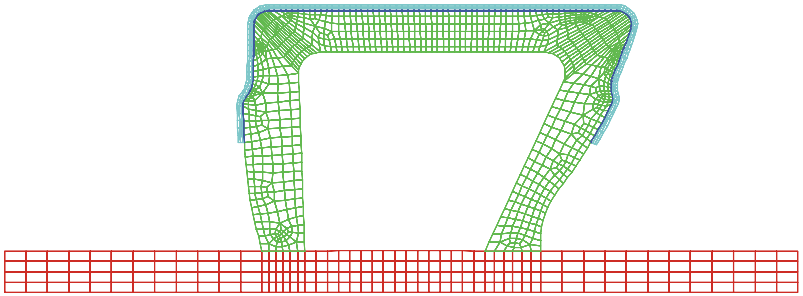
(B) “Root”



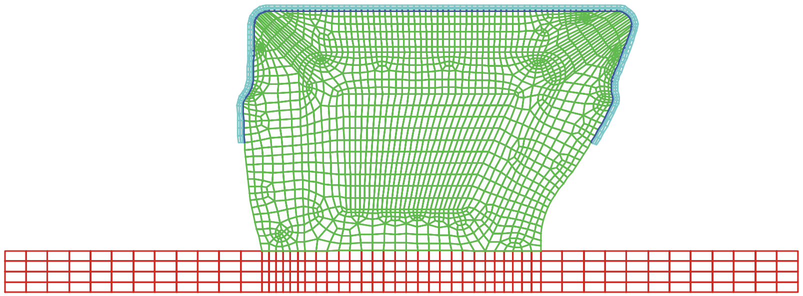
FE meshes of spar cross-sections

(hollow and solid core)

• Theses two meshes allows the study of the effect of thermal mass on cured dimensions



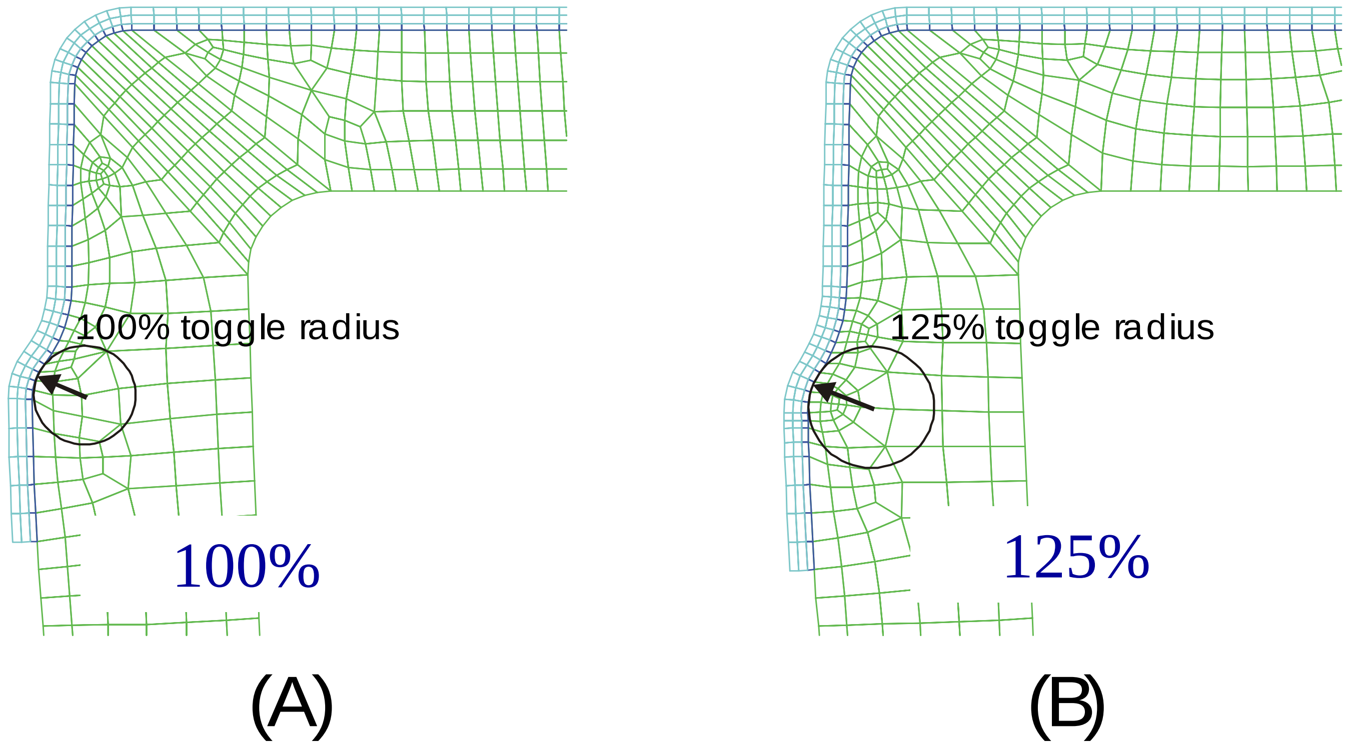
(A) Hollow Core



(B)Solid Core

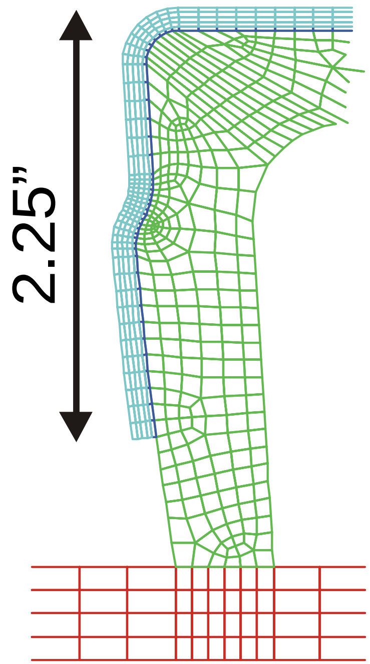
FE meshes of spar cross-sections
(toggle radius)

• To study the effect of toggle radius on cured dimensions, two FE meshed were created

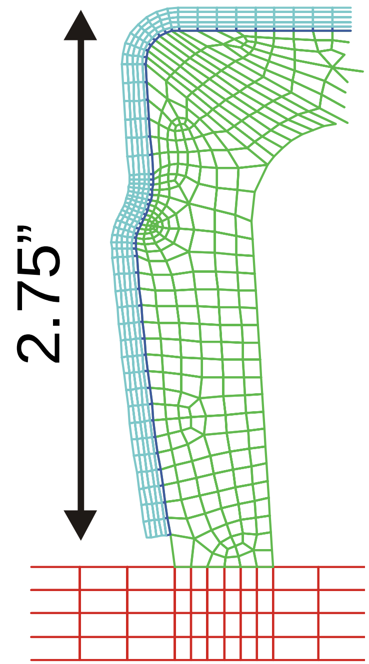


FE meshes of spar cross-sections
(flange length)

• Two FE meshes were generated to study the effect of laid-up flange length on cured dimensions



(A)



(B)

High and low settings of material factors

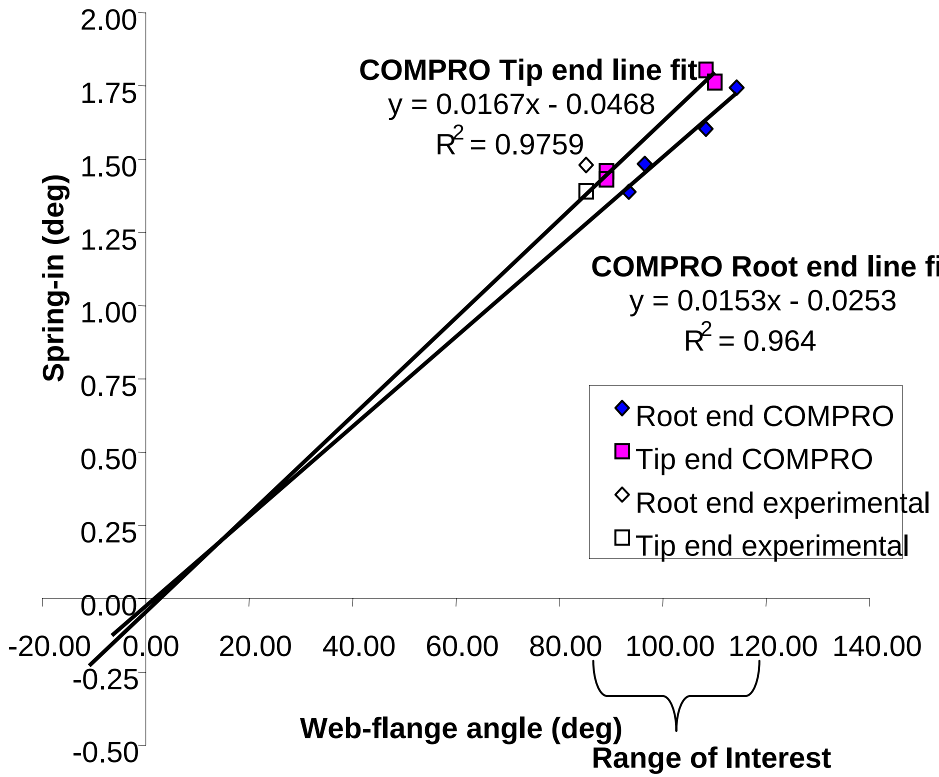
The material factors studied: cure kinetics, modulus development, resin CTE, cure shrinkage, and resin viscosity, are represented in the process model by mathematical equations. Low and high setting of these parameters were obtained by modifying the mathematical expressions

Results from numerical DOE

- After running the numerical DOE and examining the predicted flange spring-in, the following conclusions were drawn:
- The factors that had the greatest effect on spring-in were (in descending order):
  - cross-section (root or tip end)
  - resin cure kinetics (fast or slow chemical reaction)
  - amount of resin cure shrinkage
  - the interaction of timing of modulus development and resin cure shrinkage

Comparison of predicted and measured spring-in

The predicted spring-in for the base-line case at the two cross-sections (root and tip) were compared to experimental data from a prototype spar



Recommended tool compensation factor

- Based on the analysis and the good agreement with experimental data from a prototype spar, a tool compensation factor of 0.0162 degrees per degree of flange angle was recommended
- As the flange angle varies along the length of the spar, this gives a tool compensation factor that ideally should vary along the length of the spar

Outcome

- The results from the simulations were used as a basis for the design of the production tool
- Initial production parts have shown to have good dimensional control and the required dimensions for shim-less assembly

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A sensitivity analysis of the Boeing 767-400ER raked winglet front spar was performed using process modelling (COMPRO) to study the effect of material and process variables on flange spring-in. Model predictions were in good agreement with experimental results and the simulations were used as a basis for design of the production tool. The simulations provided a tool compensation factor for spring-in as well as an understanding of the sensitivity of the spring-in to variations in material and process variables.

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