Windows®-Based Software Models Cyclic Oxidation Behavior

Oxidation of high-temperature aerospace materials is a universal issue for combustion-path components in turbine or rocket engines. In addition to the question of the consumption of material due to growth of protective scale at use temperatures, there is also the question of cyclic effects and spallation of scale on cooldown. The spallation results in the removal of part of the protective oxide in a discontinuous step and thereby opens the way for more rapid oxidation upon reheating. In experiments, cyclic oxidation behavior is most commonly characterized by measuring changes in weight during extended time intervals that include hundreds or thousands of heating and cooling cycles. Weight gains occurring during isothermal scale-growth processes have been well characterized as being parabolic or nearly parabolic functions of time because diffusion controls reaction rates. In contrast, the net weight change in cyclic oxidation is the sum of the effects of the growth and spallation of scale. Typically, the net weight gain in cyclic oxidation is determined only empirically (that is, by measurement), with no unique or straightforward mathematical connection to either the rate of growth or the amount of metal consumed. Thus, there is a need for mathematical modeling to infer spallation mechanisms.

COSP is a computer program that models the growth and spallation processes of cyclic oxidation on the basis of a few elementary assumptions that were discussed in "COSP: A Computer Model of Cyclic Oxidation," *Oxidation of Metals*, vol. 36, numbers 1 and 2, 1991, pages 81-112. Inputs to the model include the selection of an oxidation-growth law and a spalling geometry, plus oxide-phase, growth-rate, cycle-duration, and spall-constant parameters. (The spalling fraction is often shown to be a constant factor times the existing amount of scale.) The output of COSP includes the net change in weight, the amounts of retained and spalled oxide, the total amounts of oxygen and metal consumed, and the terminal rates of weight loss and metal consumption.

COSP was made publicly available as a DOS-based program in 1991. The present version is a very user-friendly, object-oriented, Windows®-based program, described in "COSP for Windows: Strategies for Rapid Analyses of Cyclic Oxidation Behavior," NASA/TP-2002-211108, February 2002. The present version of COSP can be operated conveniently, while other application programs remain open, for the purpose of (a) importing experimental weight-change data, (b) storing model output data, or (c) plotting model curves. The program affords options for saving and printing information and includes a help file. Point-and-click operating features include multiple drop-down menus for input parameters, importing data, and quick generation of on-screen plots.

One of the displays generated by the program is a plot window that can show, for example, the net-weight-change curve of a chosen model. One can select from among a number of input parameters and mechanisms by tabbing down through a sequence of options, culminating with an "Okay run model" button. Plots for as many as 10 models can be displayed simultaneously for any one of six different output-parameter selections.

Another display generated by the program is a results window, which presents a summary text and a tabulated list of the calculated results. The summary text lists characteristic parameters that are helpful in describing cyclic behavior: such parameters include the maximum weight change, the number of cycles to reach maximum or zero weight, the final rate of weight loss and the fraction of scale spalled on each cycle. The table lists the calculated values for any number of outputs, for every cycle, every 10 cycles, or every 100 cycles. By use of a "copy" spreadsheet button, these tables can be pasted in other spreadsheet or plotting application programs for final storage or presentation.

This program is intended to serve as a software tool for rapidly obtaining a realistic best fit to experimental data for a given oxide type, cycle duration, growth rate, and spalling mechanism. From such a best fit, estimates of the operative parabolic-growth constant and spall constant can be easily extracted. These constants are the only two parameters that are needed to describe well-behaved cyclic oxidation according to a single specified mechanism. The program also makes it possible to estimate the total amount of material consumed by the combined oxidation and spalling process. Another benefit afforded by this program is to serve as a convenient means to observe the functional behavior of cyclic oxidation curves for any of the various input parameters — for example, by comparing families of curves corresponding to increasing values of one input parameter.

This program was developed by J. L. Smialek and J. V. Auping of **Glenn Research Center**. *Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17191.

Software for Analyzing Sequences of Flow-Related Images

Spotlight is a computer program for analysis of sequences of images generated in combustion and fluid physics experiments. Spotlight can perform analysis of a single image in an interactive mode or a sequence of images in an automated fashion. The primary type of analysis is tracking of positions of objects over sequences of frames. Features and objects that are typically tracked include flame fronts, particles, droplets, and fluid interfaces. Spotlight automates the analysis of object parameters, such as centroid position, velocity, acceleration, size, shape, intensity, and color. Images can be processed to enhance them before statistical and measurement operations are performed. An unlimited number of objects can be analyzed simultaneously. Spotlight saves results of analyses in a text file that can be exported to other programs for graphing or further analysis. Spotlight is a graphical-user-interface-based program that at present can be executed on Microsoft Windows and Linux operating systems. A version that runs on Macintosh computers is being considered.

This program was written by Robert Klimek and Ted Wright of **Glenn Research Center**. *Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland Ohio 44135. Refer to LEW-17407