

change in the position for the aircraft in a queue of all aircraft in a common stream of traffic (e.g., similar route), a change in the planned altitude profile for an aircraft, or change in the planned route for the aircraft. Flow restrictions are typically imposed to mitigate traffic congestion at an airport or in a region of airspace, particularly congestion due to inclement weather, or the unavailability of a runway or region of airspace.

A delay credit would be allocated to an operator of a flight that has accepted, or upon which was imposed, a flow restriction. The amount of the credit would increase with the amount of delay caused by the flow restriction, the exact amount depending on which of several candidate formulas is eventually chosen. For example, according to one formula, there

would be no credit for a delay smaller than some threshold value (e.g., 30 seconds) and the amount of the credit for a longer delay would be set at the amount of the delay minus the threshold value. Optionally, the value of a delay credit could be made to decay with time according to a suitable formula (e.g., an exponential decay). Also, optionally, a transaction charge could be assessed against the value of a delay credit that an operator used on a flight different from the one for which the delay originated or that was traded with a different operator.

The delay credits accumulated by a given airline could be utilized in various ways. For example, an operator could enter a bid for priority handling in a new flow restriction that impacts one or more of the operator's flights; if the bid

were unsuccessful, all or a portion of the credit would be returned to the bidder. If the bid pertained to a single aircraft that was in a queue, delay credits could be consumed in moving the aircraft to an earlier position within the queue. In the case of a flow restriction involving a choice of alternate routes, planned altitude profile, aircraft spacing, or other non-queue flow restrictions, delay credits could be used to bid for an alternative assignment.

*This work was done by Steve Green of Ames Research Center.*

*This invention is owned by NASA and a patent application has been filed. Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-15392-1.*

## Σ Spline-Based Smoothing of Airfoil Curvatures

**Spurious curvature oscillations and bumps are suppressed.**

*Langley Research Center, Hampton, Virginia*

Constrained fitting for airfoil curvature smoothing (CFACS) is a spline-based method of interpolating airfoil surface coordinates (and, concomitantly, airfoil thicknesses) between specified discrete design points so as to obtain smoothing of surface-curvature profiles in addition to basic smoothing of surfaces. CFACS was developed in recognition of the fact that the performance of a transonic airfoil is di-

rectly related to both the curvature profile and the smoothness of the airfoil surface.

Older methods of interpolation of airfoil surfaces involve various compromises between smoothing of surfaces and exact fitting of surfaces to specified discrete design points. While some of the older methods take curvature profiles into account, they nevertheless sometimes yield unfavorable results, in-

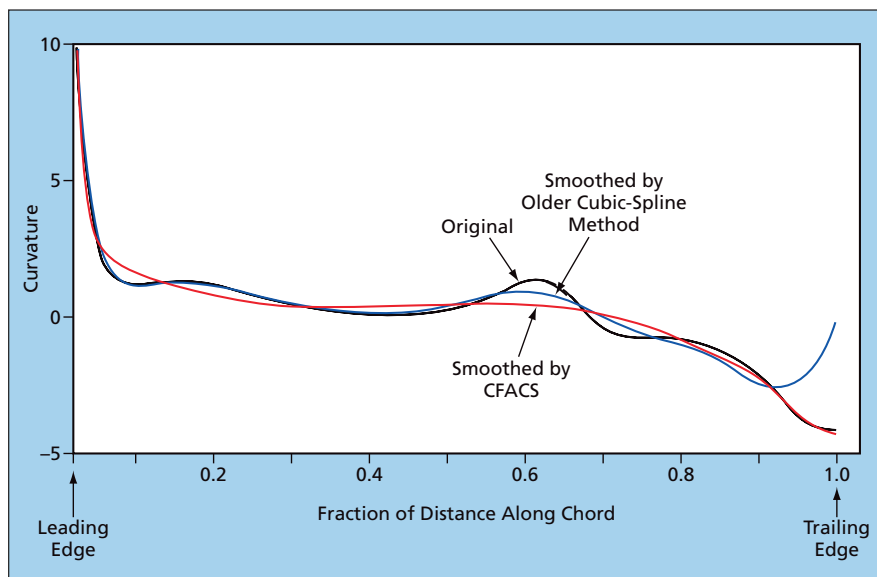
cluding curvature oscillations near end points and substantial deviations from desired leading-edge shapes.

In CFACS as in most of the older methods, one seeks a compromise between smoothing and exact fitting. Unlike in the older methods, the airfoil surface is modified as little as possible from its original specified form and, instead, is smoothed in such a way that the curvature profile becomes a smooth fit of the curvature profile of the original airfoil specification.

CFACS involves a combination of rigorous mathematical modeling and knowledge-based heuristics. Rigorous mathematical formulation provides assurance of removal of undesirable curvature oscillations with minimum modification of the airfoil geometry. Knowledge-based heuristics bridge the gap between theory and designers' best practices.

In CFACS, one of the measures of the deviation of an airfoil surface from smoothness is the sum of squares of the jumps in the third derivatives of a cubic-spline interpolation of the airfoil data. This measure is incorporated into a formulation for minimizing an overall deviation-from-smoothness measure of the airfoil data within a specified fitting error tolerance.

CFACS has been extensively tested on a number of supercritical airfoil data



**Curvature Profiles** were computed for the lower surface of a supercritical airfoil. The CFACS profile closely fits the original profile at the trailing edge, whereas the profile generated by the older cubic-spline smoothing method exhibits substantial bias away from the original profile at the trailing edge.

sets generated by inverse design and optimization computer programs. All of the smoothing results show that CFACS is able to generate unbiased smooth fits

of curvature profiles, trading small modifications of geometry for increasing curvature smoothness by eliminating curvature oscillations and bumps (see figure).

*This work was done by W. Li and S. Krist of Langley Research Center. Further information is contained in a TSP (see page 1). LAR-17227-1*

---

## ② Reducing Spaceborne-Doppler-Radar Rainfall-Velocity Error

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A combined frequency-time (CFT) spectral moment estimation technique has been devised for calculating rainfall velocity from measurement data acquired by a nadir-looking spaceborne Doppler weather radar system. Prior spectral moment estimation techniques used for this purpose are based partly on the assumption that the radar resolution volume is uniformly filled with rainfall. The assumption is unrealistic in general but introduces negligible error in application to airborne radar systems. How-

ever, for spaceborne systems, the combination of this assumption and inhomogeneities in rainfall [denoted non-uniform beam filling (NUBF)] can result in velocity measurement errors of several meters per second.

The present CFT spectral moment estimation technique includes coherent processing of a series of Doppler spectra generated in a standard manner from data over measurement volumes that are partially overlapping in the along-track direction. Performance

simulation of this technique using high-resolution data from an airborne rain-mapping radar shows that a spaceborne Ku-band Doppler radar operating at signal-to-noise ratios  $>10$  dB can achieve root-mean-square accuracy between 0.5 and 0.6 m/s in vertical-velocity estimates.

*This work was done by Simone Tanelli, Eastwood Im, and Stephen L. Durden of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact [iaoffice@jpl.nasa.gov](mailto:iaoffice@jpl.nasa.gov). NPO-40590*