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Design and Testing of Low Sonic Boom Configurations and an Oblique All-Wing Supersonic Transport

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December 1991 to June 1992

Sonic Boom Minimization

From December of 1991 to June of 1992 applied aerodynamic research support was given to the team working on Low Sonic Boom Configurations in the RAC Branch at NASA Ames Research Center. This team developed two different configurations, a conventional wing-tail and a canard-wing, in an effort to reduce the overpressure of shock waves, and the accompanying noise, which are projected to the ground from supersonic civil transport aircraft.

Because the work done for this project is considered to be competitively sensitive technology, only a generic description is given here. Pictures are not allowed. For a more detailed account of the work please see references 1 and 2.

The design requirements stated that the aircraft design should accommodate 300 passengers, and have a range of 5,500 nautical miles while producing less than 95 PLdB (perceived loudness, in decibels). In striving towards these goals the configurations were designed with the following iterative procedure:

- Perturb the geometry
- Analyze with Computational Fluid Dynamics (CFD) Code
- Extract "near-field" boom signature
- Extrapolate signature to ground
- Calculate the noise level (PLdB)
- Evaluate mission performance

Perturbations to the geometry included variations on the wing and canard (sweep, twist, dihedral, crank point, longitudinal position, and airfoil sections) as well as the body (area-ruling, camber) and nacelles (number, size, position, and shape). The resulting near-field sonic boom signatures were calculated using two different CFD codes, HFLO4 (ref. 3, 4) and TranAir (ref. 5). The near-field signatures were then extrapolated to a ground-level distance with ANET (ref. 6). The perceived loudness of the signature at the ground was then calculated with the codes ADDRISE and PLdB (ref. 7, 8). Finally, the mission performance of the designs was analyzed with the ACSYNT code (ref. 9, 10, 11) by members of the FAS Branch at Ames. This manual iteration scheme was time consuming, but produced two designs which met the noise constraints and which were subsequently tested in the NASA Ames 9- by 7-foot Supersonic Wind Tunnel.

In addition to working on the above design process, MCAT support also included efforts in code validation (TranAir and HFLO4), development of an automated grid generation scheme for the TranAir code, and design and integration of the propulsion systems.

July 1992 - December 1994

Oblique All-Wing

The work in sonic boom minimization led to the investigation of the Oblique Flying Wing, as this concept was thought to have low sonic boom characteristics resulting from favorable combinations of lift and volume distributions (ref. 12, 13). Analyses of a simple OFW showed tentative agreement, but left questions as to the realism of this concept in the role of a supersonic civil transport.

During the period of July 1992 - December 1994 applied aerodynamic research support was given to the Oblique All-Wing Design Group in the RAC branch of NASA Ames Research Center. This support focused on the preliminary design of an OAW Supersonic Transport aircraft, and a corresponding wind-tunnel model that was tested in the NASA Ames 9- by 7-Foot Supersonic Wind Tunnel. The project was a cooperative effort involving NASA, Boeing, McDonnell Douglas, and Stanford University, with a main goal of determining the cruise performance (lift/drag ratio) of a realistically configured OAW.

In order to achieve an acceptable level of realism, it was necessary to consider many issues of design practicality. For instance, there needed to be a viable propulsion system, adequate control surfaces, landing gear, provisions for 450 passengers, and fuel to fly 5,000 nautical miles. The aircraft had to be stable, structurally sound, and needed to fit into airports across the world. Though much of the support given was directed specifically towards integration of the propulsion system, there were notable contributions to many aspects of the configuration design, wind-tunnel model and wind-tunnel test.

Because the work done for this project is considered to be competitively sensitive technology, only a generic description is given here. Pictures are not allowed. For a more detailed account of the work please see references 20 - 22.

The project work began in July of 1992 with OAW-0, the zeroth-order OAW configuration, as a starting point (ref. 14). By July 1993 the group had developed OAW-1 and OAW-2 designs, and was well on the way to freezing the eventual OAW-3. Between OAW-0 and OAW-2, support was given to the airfoil design optimization and wind design optimization efforts. The main tools used in these efforts were the Computational Fluid Dynamics (CFD) codes FLO6QNM (ref. 15), LBAUER, (ref. 16) R22OPT (ref. 17, 18), TranAir (ref. 5), and OVERFLOW (ref. 19). A thorough account of the wing design is given in reference 20. Other support given during this period was related to integration of the propulsion system. By the end of the OAW-2 work, a study of nacelle shapes and placements was nearly complete. Using TranAir, several nacelle shapes were analyzed in a matrix of positions underneath the most current OAW wing configuration, in an effort to maximize favorable nacelle-nacelle interference and minimize unfavorable nacelle-wing interference.

Work from July of 1993 to July of 1994 included the completion of the baseline propulsion-integration work, and a presentation thereof at the First NASA/Industry High Speed Research Propulsion Airframe Integration Workshop in Cleveland, OH (ref. 21). This work resulted in an 8.3% savings in inviscid drag for the OAW-2 wing-nacelles configuration, compared to the OAW-0 wing-

nacelles configuration. The propulsion integration work continued with the design of the pylons. The first analysis in TranAir showed that the pylons had more than three times the expected drag increment. Analysis of a modified pylon showed only modest improvement (10% of the pylon increment) and prompted designers at Boeing to rethink their minimum-thickness structural constraint on the pylon. Using a new structure and stronger materials, the thickness of the engine pivot mechanism was cut in half, allowing for a thinner pylon. Unfortunately, this was done after the contracted machine shop had finished building the pylons for the wind-tunnel model. A retro-fit pylon was designed to try to take advantage of the reduced minimum thickness constraint. Even though it was not an optimal shape for the given thickness (as it had to fit the existing model) this thinner pylon was estimated to save nearly 50% of the incremental drag. It would have to be fabricated in the RA Division machine shop, however, as there was no money or time to have it done outside. In the end, the Division shop was unable to build the thinner pylon, owing to the very fine edges and small angles in the geometry. As a result, this pylon never got tested in the wind tunnel.

In addition to the propulsion integration work, MCAT was simultaneously immersed in many other research activities. After analyzing a vertical fin design from McDonnell Douglas and finding poor pressure contours and trim results, the design of an improved fin was undertaken. Following the determination of the shape and position of the fins (upper and lower), the fin incidences were tuned using TranAir analyses in order to achieve yaw trim and equal loading between the upper and lower fins. The effect of fin twist was looked at briefly as well. Subsequently, a TranAir analysis of the full configuration was performed for OAW-3 with wing, vertical fins, nacelles and pylons. This was the first time the whole aircraft had been analyzed with a nonlinear CFD code.

Viscous analysis of the OAW was of obvious interest as well. TranAir, with its boundary layer options, was tried but proved to give poor results. The boundary layer implementation in TranAir is not well suited for highly swept, or forward swept wings. Attention then turned to OVERFLOW, a Navier-Stokes code with overset (chimera) grid capability which would allow it to handle such a complex configuration. OVERFLOW was run on the wing alone, the wing with fins, and the full configuration, with and without the wind-tunnel mounting blade included, for analyses on a total of six configurations. In some cases the research support entailed construction of the chimera grids, running of the solutions, and post processing of the data. In other cases, these three steps were shared among researchers.

The results from OVERFLOW were compared with Pressure Sensitive Paint (PSP) and experimental force and moment data (ref. 22) during the wind-tunnel test, in a demonstration of the IofNEWT program (Integration of Numerical and Experimental Wind Tunnels). It is interesting to note that some of the moments measured in the wind tunnel were significantly different from those predicted by the CFD analyses of the wing without the wind-tunnel mounting blade. This prompted the running of more CFD analyses *during the test* to ascertain the increments in performance due to the presence of the blade. The data from the with-blade CFD analyses showed remarkable agreement with wind-tunnel data, as witnessed by researchers at Ames, and others from Boeing and McDonnell Douglas who participated via the new Remote Access Wind Tunnel (RAWT) link.

The balance of OAW research support provided by MCAT related directly to the wind tunnel test. Work included the following:

- Reconciling the design specifications with the wind-tunnel model as built (e.g., comparing the designed pressure tap locations with those measured, and correcting the corresponding databases for use in the test).
- Helping set up the test run schedule.
- Working as OAW Project Shift Engineer, overseeing the run schedule and tunnel operations
- Aiding in the equipment setup and operation for the PSP, IofNEWT and RAWT systems.
- Development of a complex of codes which can be used to take computational results from OVERFLOW analyses and put them into a CDD (CAPAIR Deliverable Database) for direct comparison to wind-tunnel data.

Research support will continue through the completion of the documentation of the design effort.

December 1994 - January 1995

Sonic Boom Minimization

At the end of the OAW project, research efforts returned for a short while to the study of the Sonic Boom problem, this time with code development efforts in the new AAC Branch at Ames.

Working with Dr. Samson Cheung, I was tasked with enhancing the capabilities of an automated grid generation scheme for the UPS3D code. Along with the improvements made to the grid generation scheme (newgrid.f) support was also given by learning and applying the UPS3D code itself.

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