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MACH SWEEP TECHNIQUE FOR STORE SEPARATION WIND TUNNEL TESTING

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ABSTRACT

The conventional approach for store separation wind tunnel testing consisted of testing the store in proximity to the aircraft at various store and aircraft positions and attitudes. These tests were conducted at specified Mach numbers, usually in the transonic speed range. This paper demonstrates the mistake of using a pre-selected range of Mach numbers for the wind tunnel testing, and describes the advantages of using the Mach Sweep approach. Mach Sweep is a calibration technique that finds appropriate sampling points for different wind tunnels so that store trajectory simulations don't use data from regions where force and moments exhibit large variation.

INTRODUCTION

JSOW Store Separation Wind Tunnel test

More than twenty years ago the Joint Stand-Off Weapon (JSOW) store was certified on the F-18C/D aircraft, Figure 1. Wind tunnel Captive Trajectory System (CTS) grid and trajectory data were collected at the CALSPAN and the David Taylor Research Center (DTRC) transonic wind tunnels. Since the CALSPAN tunnel was 8 ft. wide by 8 ft. high and the DTRC tunnel was 10 ft. wide by 7 ft. high, tunnel size differences were not considered significant. Carriage loads data (i.e. the store mounted on the wing pylon) were also collected. At subsonic Mach numbers, the two sets of test data were in good agreement with each other. However, at M = 0.95, there was a large discrepancy between the two sets of test data.

Figure 1 JSOW mounted on the F-18C outboard Pylon

As may be seen in Figure 2, the CALSPAN incremental pitching moment (CLM - CLM0) grid data were more than twice as large as those at DTRC. Grid data are used in conjunction with large scale freestream data to compute store trajectories, where CLM0 is the pitching moment at the largest Z location from the store carriage, and assumed to be outside of the influence of the aircraft flow field.

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In addition, while the CALSPAN measured load at carriage was in agreement with the Captive Trajectory System (CTS) data, the DTRC carriage load is much larger than that measured by the CTS system.

The yawing moment data (CLN-CLN0) shown in Figure 3 exhibited even more extreme variation. The CALSPAN data showed a yawing moment that was nearly three times that of the DTRC data. Again, there was a large difference in the carriage yawing moment for the DTRC data, while the CTS and carriage data at the CALSPAN facility were in good agreement.

Since the predicted trajectories using DTRC data were more benign at M = 0.95, the CALSPAN data were used for the flight test program. Excellent agreement between the pre-flight predictions and the flight test were achieved [Cenko, 1991].

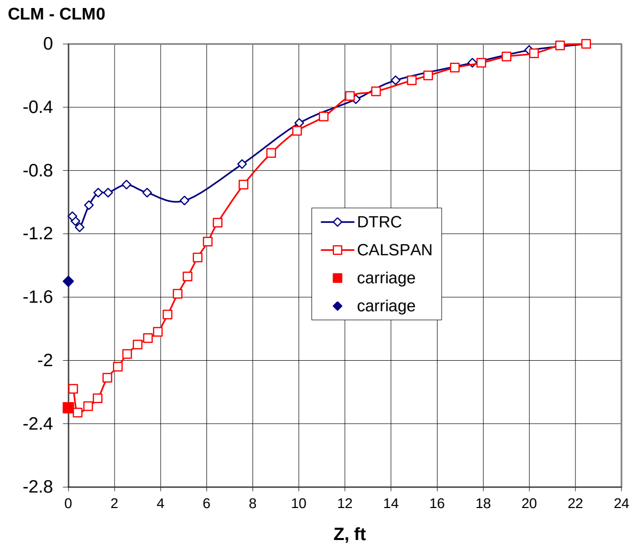

Figure 2 JSOW Pitching Moment

The large discrepancies between the CTS and Carriage loads data were examined during a separate wind tunnel entry, where a dummy sting was used to examine whether sting effects could be used to explain the differences. Although the dummy sting indicated that sting effects could explain the differences between CTS and Carriage data [Cenko, 1994], the differences between the DTRC and CALSPAN wind tunnel data were still unexplained.

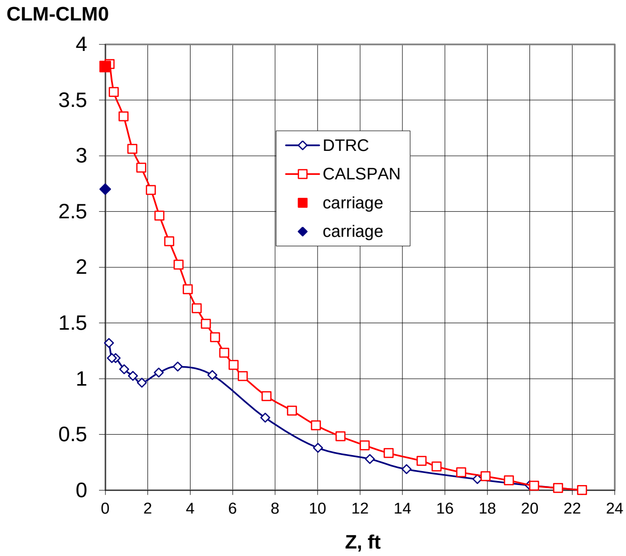

Figure 3 JSOW Yawing Moment

MACH SWEEP TECHNIQUE

Wind tunnel CTS grid data for several weapon systems on the F/A-18C/D aircraft were collected during subsequent years. In particular, wind tunnel test data and CFD predictions were compared for the F-18C/D aircraft with a fuel tank on the inboard pylon and a 2000 lb. bomb on the outboard pylon shown in Figure 4 [Cenko, 1998].

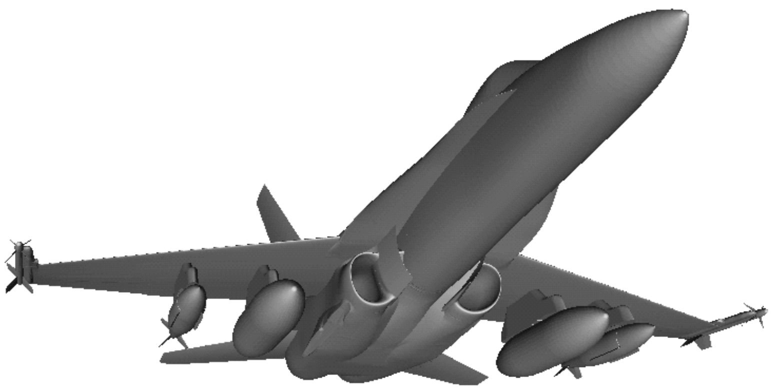

Figure 4 F/A-18C/D Aircraft Configuration with Fuel Tanks Inboard

As may be seen in Figure 5, there is a dramatic change in the pitching moments with Mach number for three different stores, the MK-84, SLAM-ER and GBU-31.

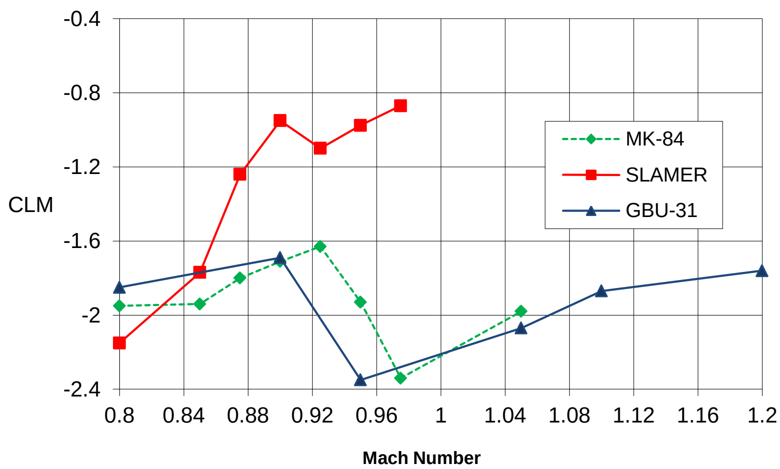

Figure 5 Pitching Moment Change with Mach Number

The largest (negative, nose down) pitching moment for the SLAMER occurs at M = 0.80, while that for the MK-84 and GBU-31 occurs between 0.95-0.97. The yawing moment for the three stores also shows a large variation with Mach number, Figure 6.

In this case the yawing moment for the SLAMER increases by 50% as the Mach number increases from 0.88 to 0.90.

These test data helped explain the discrepancy seen in the CALSPAN and DTRC test data for the JSOW store. It is important to note that the wind tunnel attempts to represent the actual aircraft flight condition. The nominal wind tunnel Mach number relative to free flight can obviously change depending on the tunnel size, blockage, flow angularity, etc. Since it's impossible to guarantee that the flight test will be conducted at a specific Mach number, particularly in a dive, the store separation engineer attempts to simulate the worst case condition.

Clearly the effective Mach number at the DTRC was facility was sligthly different than that at CLASPAN, even thought the set point Mach number was 0.95 in both.

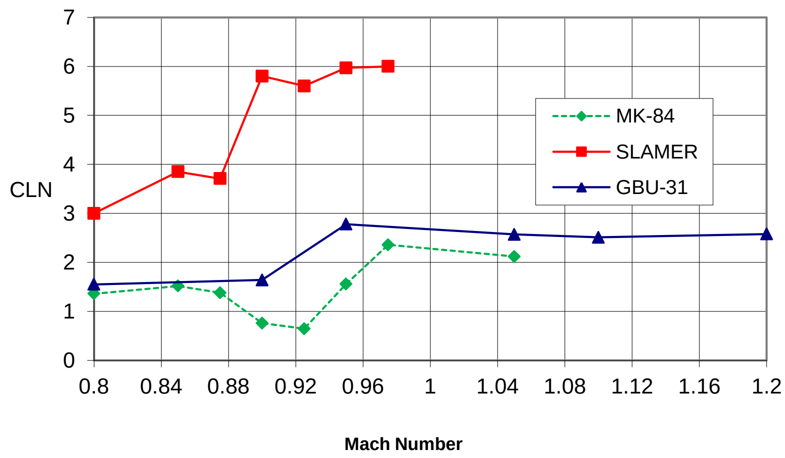

Figure 6 Yawing Moment Change with Mach Number

Susbsequent store separation tests have used the Mach sweep technique. The Mach sweep store separation test technique uses a small incremental build up in tunnel Mach number in the transonic range (i.e. M=0.02 for M = 0.80 to 1.2) with the store positioned in carriage by the CTS system.

As may be seen in Figure 7, the pitching moment for the GBU-32 store changes by more than 100% between M = 0.90 and 0.92.

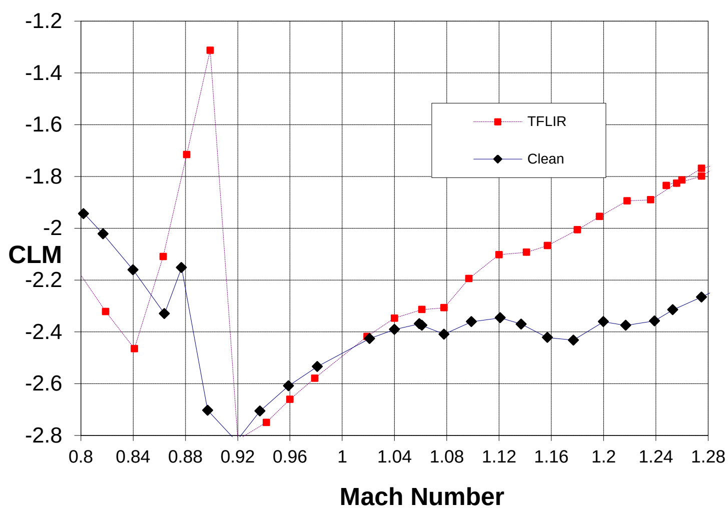

Figure 7 GBU-32 Pitching Moment Change with Mach Number

Furthermore, aircraft configuration changes have a significant impact on the store aerodynamics. The large yawing moment effect of the Targeting Forward Looking Infrared (TFLIR) external pod relative to the clean aircraft can also be easily seen in Figure 8.

One major advantage of the Mach sweep technique is that it is easy to identify the critical Mach numbers for the remainder of the test. For the GBU-32 test, most of the grid data were taken only at M = 0.85, 0.95 and 1.20; an excellent match with the flight test data were achieved [cenko, 2010] .

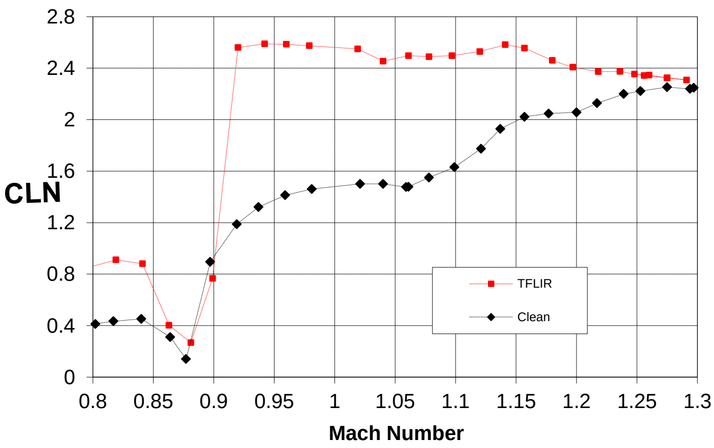

Figure 8 GBU-32 Yawing Moment Change with Mach Number

Computational Verification

Moment effects due to targeting pods were computationally examined over several years. In particular, it has been shown [Godikson, 2008] that minor changes in targeting pod geometry could have an considerable effect on the resultant stores trajectory. For the pitching and yawing moment, the location and strength of the shock hitting the store tail could make the difference between a safe trajectory, or one where the store might impact the aircraft.

As may be seen in Figure 9, the shock wave from the end of the Advanced Targeting Forward Looking Infrared (ATFLIR) external pod hits the store tail, while that from the Litening pod, at the same Mach number, misses it. Theses computational results were verified by wind tunnel testing.

It is clear that minor changes to the aircraft configuration can have a significant impact on the resultant trajectories. However, these effects can be computationally predicted. An extensive long term effort to determine improvements in design methodologies for installing target pods has been conducted by the United States Naval Academy [Godiksen, 2008, Obrien, 2010, Simpson, 2011, Snyder, 2011,2012].

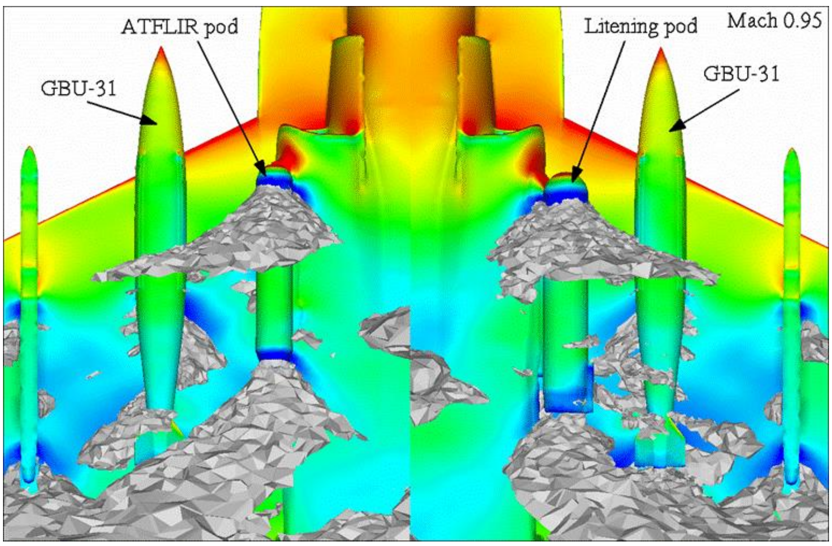

Figure 9 F/A-18C/D Shock Pattern at M = 0.95

Store freestream effects can also be significantly impacted by the attachment hardware. It has been shown [Snyder, 2011, Doig, 2013], both computationally and by wind tunnel testing, that a strut sting (commonly used for bomb bays), can have a significant inpact on store freestream characteristics. As may be seen in Figure 10, the shock wave from the strut attachment interferes with the store tail, significantly changing the store pitching and yawing moments.

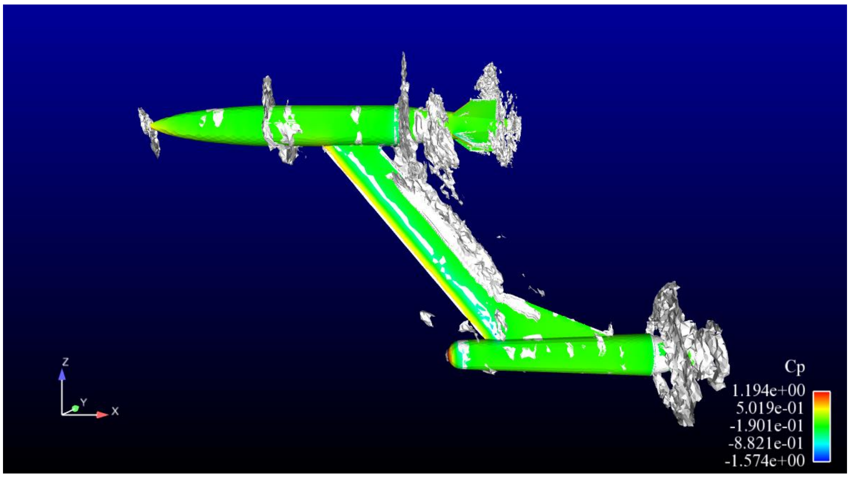

Figure 10 Shock Pattern on Generic Strut Store at M = 0.85

Mach Sweep Effects on Aircraft

Wind tunnel tests have been conducted on aircraft configurations for over a hundred years. Transonic tests have usually been at pre set test Mach numbers. How is it that the Mach Sweep effect has not been observed for aircraft testing?

Some idea of the Mach Sweep effect can be observed by looking at the CFD solutions as the Mach number is increased. The shock wave forms at a lower transonic Mach number, and then progresses aft until it reaches the end of the wing. When the shock from an adjacent store hits another store there has to be a significant impact on the moments. For the aircraft as a whole, this effect could be much less significant.

However, differences in aircraft forces and moments at the same Mach number in different tunnels have been recently reported [Deloach, 2013]. Could these differences be resolved by using the Mach Sweep technique?

Conclusions

Mach Sweep is a calibration technique that finds appropriate sampling points for different wind tunnels so that store trajectory simulations don't use data from regions where force and moments exhibit large variation. For the past fifteen years this technique has been successfully used for various stores on numerous attack aircraft. In particular, the critical Mach numbers for wind tunnel and flight testing were identified, providing considerable savings in time and cost. It also appears that Mach number effects can also play a role in wind tunnel testing for aircraft.

Acknolodgements

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