Steve Savoie’s Winter ’99 Scale Project — Northrop’s X-4 *Bantam*

It was already dark outside when the ’phone rang. On the other end was Steve Savoie, excitedly relating the recent successful flight of his scale U-2. Buoyed by a spectacular slope flight, he went on to relate his idea for another scale project — Northrop’s X-4 *Bantam*. Steve thought he might be proposing an outrageous idea, but we assured him success was more than a possibility.

Our foundation for this upbeat attitude is derived from the efforts of Giuseppe Ghisleri. Giuseppe, who lives in Italy, built a near scale X-4 for flying on a local slope. The model is typical PSS construction and approximately 1/6 scale. The foam wings use the Eppler 224 at the root, Eppler 230 at the tip, and are sheeted with balsa. The blue foam fuselage is covered with fiberglass. The resulting model is lightweight and thermals easily in the conditions at Grone, an Alpine flying site which has a sun-facing rock face and a lot of thermal activity. The model will spin when given full up elevator and full aileron, but recovery is automatic upon release of the sticks.

Steve, somewhat surprised by our very positive attitude, went on to say that although he would be constructing the model, he thought other *RCSD* columnists might at some point be involved in some aspect of the project.

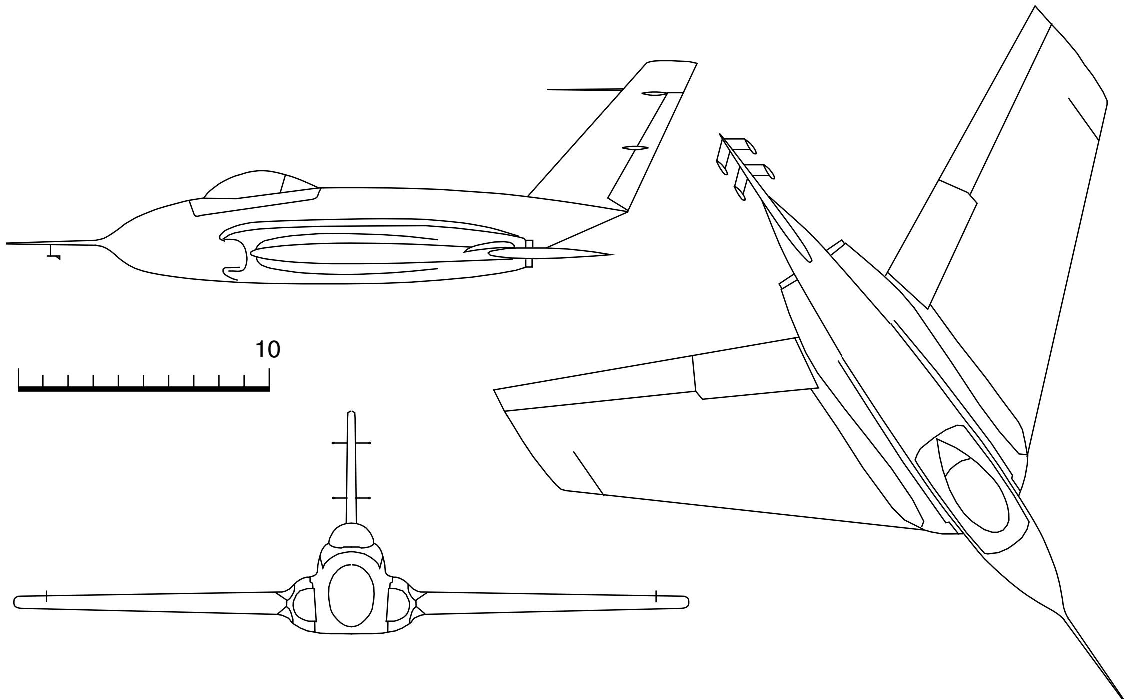
In the end, he “hired” us as consultants to do three things: (1) choose an airfoil for the wing, (2) compute how much, if any, twist should be used, and (3) determine a safe CG location. This month’s column is devoted to explaining our responses to these three requests. Because the required wing twist is directly related to the aerodynamic characteristics of the airfoil(s) used — zero lift angle and pitching moment — choosing an airfoil is the first task to be tackled.

Choosing the Airfoil

As long term readers know, we are great proponents of the EH sections for swept wing tailless models. To reiterate what we’ve said previously about these sections, they have low pitching moments, docile stall characteristics, and lend themselves to reasonable modifications of camber and/or thickness.

The original X-4 used the NACA 0010-64 section. This is a symmetrical profile of 10% thickness. Steve would like very much to be able to thermal this model, and he asked if we could recommend a section with about 2% camber. The EH 2.0/10.0 provides the correct thickness for this model and has sufficient camber to be considered a soaring section.

Using the EH 2.0/10.0 directly does pose a difficulty, however. Because of the camber, the curvature of the upper surface is noticeably greater than that of the NACA 0010-64. The leading and trailing edges of the wing root will be slightly lower on the model than on the full size aircraft. This can be seen in Figure 1-A.



NORTHROP X-4 *BANTAM*

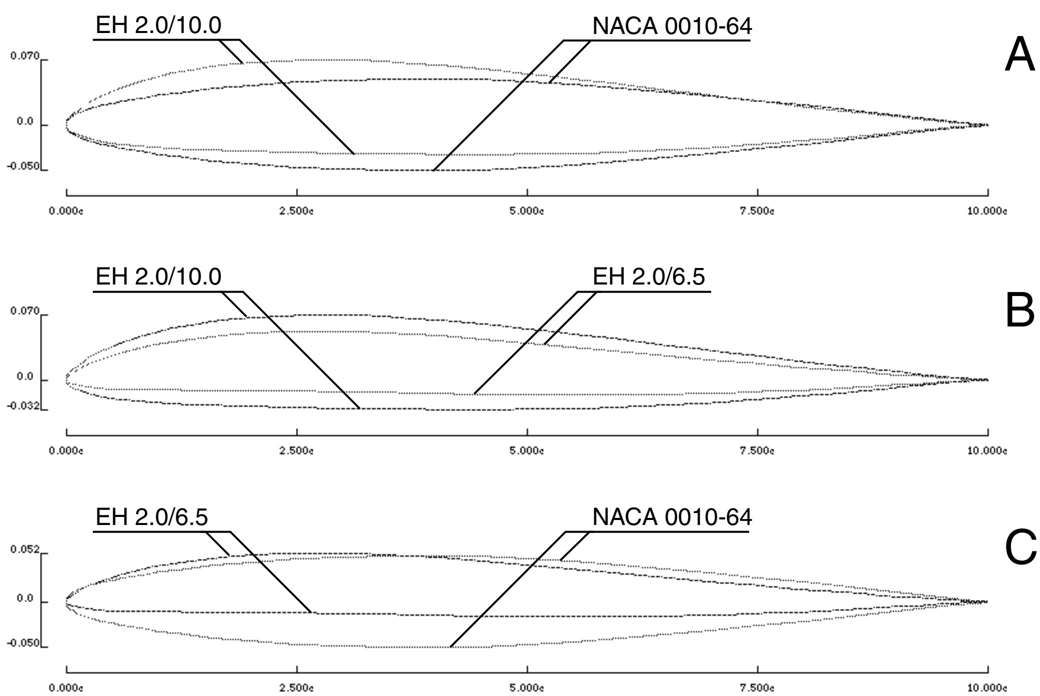


Figure 1

To reduce this difference, we slimmed the EH 2.0/10.0 to 6.5% thickness. See Figure 1-B. This modification should very much improve the appearance of the model when viewed from above, as the resulting contour is closer to that of the NACA 0010-64 and the location of the leading and trailing edges is more closely aligned to the original. See Figure 1-C. The thinning procedure flattens the lower surface somewhat, but certainly not in an objectionable way when viewed from a distance or in flight. The lower surface remains convex at 6.5% thickness, but does becomes concave if the section is thinned further.

Despite being just 6.5% thick, the wing has a chord large enough to ensure good spar height and plenty of clearance for standard size servos. Aerodynamically speaking, this thinning of the airfoil reduces the drag produced by the wing, but the pitching moment remains the same because the camber line has not been altered. Steve, of course, will have to make the eventual choice for the wing section, EH 2.0/10.0 or EH 2.0/6.5, based on how comfortable he is with building and flying a thin section.

Computing the Necessary Wing Twist

The X-4 data used in Table 1 was taken from "The X-Planes," while aerodynamic data for the EH 2.0/6.5 was derived from EH 2.0/10.0 polars published on the UIUC web site. The data from Table 1 was input into the Panknin twist formula. The results are shown in Table 2.

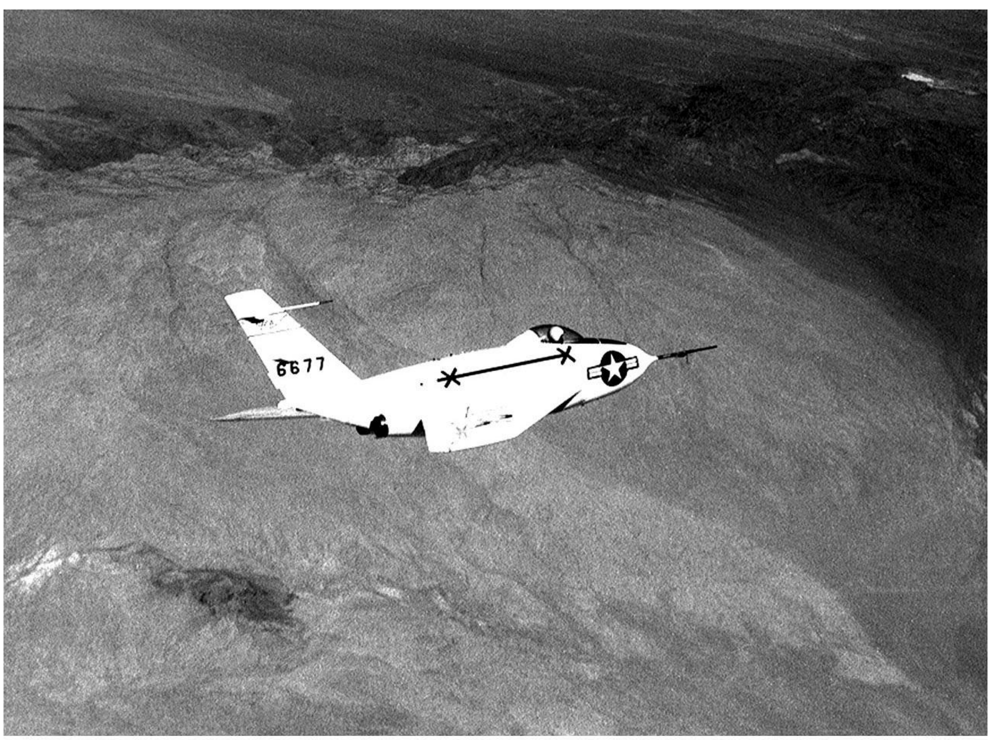
Table 1: Input Data for Twist Computation

Parameter	Dimension
Span	26.83
Root chord, projected to ℄	10.25
Tip Chord	5.0
Sweep angle (1/4 chord)	38 degrees
EH 2.0/6.5 zero lift angle, $a_{l=0}$	-1.0 degrees
EH 2.0/6.5 pitching moment, c_m	~0.00

The design coefficient of lift, $C_{Ldesign}$, is the coefficient of lift at cruise velocity. Travelling between thermals should be accomplished at neutral trim. Slow speed flight and thermalling should always be achieved by inputting some amount of up elevator, while high speed flight should require only a very small amount of down trim.

Keeping the above in mind, the wing cores should be cut in one piece with 1.6 to 2.0 degrees of twist (washout; i.e., leading edge down). Thermalling then requires some amount of up trim.

Dryden Flight Research Center E-359 Photographed 8/50
The X-4, a semi-tailess airplane that provided data important for the development of other high-performance aircraft.



Dryden Flight Research Center E-17402 Photographed 1967
X-4

Table 2: Required Twist

$C_{Ldesign}$	Twist
0.1	-1.6 degrees
0.2	-3.1 degrees
0.3	-4.7 degrees
0.4	-6.2 degrees
0.5	-7.8 degrees
0.6	-9.3 degrees

Determining the Proper CG Location

Determining the mean aerodynamic chord, MAC, of a swept wing tailless airplane would seem to be fairly simple, and indeed it is. The difficulty in placing the CG arises when attempting to determine an adequate static margin, the distance between the neutral point (25% MAC) and the CG. The problem is twofold: (1) the aerodynamic center must be established, and (2) the static margin determined. Let's take a look at the latter difficulty first.

If the static margin is too large, the elevator is relatively insensitive. The aircraft is too stable in pitch. Large amounts of up elevator will be required to achieve level flight, and performance will suffer as a result. In the worst case, there will be insufficient up elevator travel to prevent an unrecoverable dive.

On the other hand, if the static margin is too small, the elevator will be overly sensitive. The aircraft will be unstable in pitch. This can lead to erratic flight, even when very small control inputs are given, and pilot induced oscillations may cause loss of the aircraft. In the worst case, the aircraft is uncontrollable unless a "black box" with a high feedback frequency is put into use. The designer strives to keep pilot input to an acceptable level while reducing the static margin to the minimum.

This leads us back to the first difficulty. Since the static margin is always measured in relation to the aerodynamic center, it is imperative that the aerodynamic center be located accurately. You do not under any circumstances want to have the CG behind the aerodynamic center. For safety, modellers usually locate the aerodynamic center as accurately as possible and begin flight testing with a static margin which is known to be larger than will eventually be found practical.

Interestingly, the X-4 was first flown with a too small static margin. The aerodynamic center is assumed to be at 25% MAC. On its maiden flight, the X-4 CG was set at 22% MAC, a static margin of 3%, and longitudinal instability was in evidence. The instability disappeared when theCG was relocated to 19.7% MAC, 5.3% static margin, and this static margin was retained for

Table 3: Planform Geometric Data

Dimension	Value
Mean Chord, $\bar{c}$	7.625
Taper Ratio	0.488
Aspect Ratio	3.52
Aerodynamic Center	7.2 behind apex

Table 4: CG Location vs. Static Margin

Static Margin	CG
0.03	6.97 behind apex
0.04	6.89 behind apex
0.05	6.82 behind apex
0.06	6.74 behind apex
0.07	6.67 behind apex
0.08	6.59 behind apex

all subsequent flights. It's interesting to note that Giuseppe Ghisleri's model flies well with a static margin of 5% MAC, almost exactly that of the full size aircraft.

For Steve's model, we're recommending an initial static margin of 6% MAC. This will require a small amount of up trim for level flight. As flight testing progresses, the CG can be moved aft while elevator sensitivity is evaluated and up trim reduced. The static margin should eventually be found to be around 5% MAC. See Table 3 for planform geometric data and Table 4 for an evaluation of CG location vs. static margin.

Additional Items of Interest

The X-4 was not designed to reach velocities greater than sound. It's primary purpose was to determine if sonic and supersonic flight could be made easier by the elimination of the interference between the wing shock wave and the horizontal stabilizer. Despite a subsonic maximum attained speed of Mach .94, the X-4 proved to be a good research vehicle, fulfilling all design expectations. Two were built, and both survived their flying years without a single major mishap.

The split drag brakes on the X-4 were large, and both surfaces could be opened to 60 degrees.The increase in drag was dramatic, and the glide ratio dropped to below 3:1 when the brakes were fully open. The X-4 was used as a testbed to simulate the landing patterns of aircraft still in the design stage, notably the X-15. We recommend Steve construct operable drag brakes on his model. In a recent e-mail message, he mentioned he had designed a mechanism for scale operation of this feature.

The X-4 was also used as a research vehicle for exploring blunt trailing edges. This aspect of X-4 flight testing was initiated in response to porpoising at speeds of Mach .87 and above, and a tendency to tuck at speeds above Mach .71. The investigation first involved blunting the trailing edge of the drag brakes. This was accomplished by inserting wooden blocks between the upper and lower surfaces so they could not be fully closed. This opened the upper and lower flap surfaces five degrees. The results were promising, and balsa blocks were inserted in the trailing edge of the ailerons as well. These blocks were large enough to make the trailing edge thickness one half of the thickness at the hinge point (~80% chord). The porpoising and tuck were substantially inhibited, and Scott Crossfield was able to safely reach Mach 0.94, the highest speed recorded for the aircraft. Despite the possibility of making construction easier, such thick trailing edges on a model are not practical and would markedly hurt performance.

The name “Bantam” came from the aircraft’s diminutive size. Nearly every part of the aircraft could be accessed by someone standing on the ground. The X-4 remains one of the smallest X-planes built.

Thanks to Steve for offering us the opportunity of participating in his scale project. Being such enthusiasts of tailless aircraft, we of course had an initial interest in the project. But once we got involved in learning about the aircraft, our interest rapidly intensified. We were quite surprised by its unique features and the extent of the X-4 research environment. We can’t wait for the build-along articles to start!

Giuseppe Ghisleri and his X-4 at a slope in Italy.

References:

Miller, Jay. The X-Planes: X-1 to X-31. Orion Books, New York. 1988.

UIUC Airfoil Coordinate Database.
<http://amber.aae.uiuc.edu/~m-selig/ads/coord_database.html>