X-31 Quasi-Tailless Flight Demonstration

By:

Peter Huber, Deutsche Aerospace

Harvey Schellenger, Rockwell

OUTLINE

- What is Quasi-Tailless
- Objectives
- Aerodynamic of Tailless X-31
- Quasi-Tailless Control Law
- Flight Test Results
- Summary

WHAT IS QUASI-TAILLESS

Quasi-tailless stands for an in-flight simulation of an aircraft without a vertical tail, respectively with a vertical tail reduced in size. The lateral / directional stability characteristics of a tailless / reduced tail configuration are achieved by feeding back sideslip , roll rate and yaw rate via destabilization gains to rudder and ailerons.

Thrust vectoring is used for directional augmentation and control to reestablish desired lateral / directional flying qualities.

QUASI-TAILLESS FLIGHT DEMONSTRATION

WHAT IS QUASI-TAILLESS

- **A flight control system mode that uses rudder and ailerons to destabilize the aircraft in order to obtain directional stability characteristics as if the vertical tail were actually removed respectively reduced in size**
- **Thrust vectoring is used for directional control to reestablish desired lateral/ directional flying qualities**

Deutsche Aerospace

Rockwell

OBJECTIVES

The primary objective of the quasi-tailless flight demonstration is to demonstrate the feasibility of using thrust vectoring for directional control of an unstable aircraft. By using this low-cost, low-risk approach it is possible to get information about required thrust vector control power and deflection rates from a inflight experiment as well as insight in low-power thrust vectoring issues.

The quasi-tailless flight demonstration series with the X-31 began in March 94. The demonstration flight condition was Mach 1.2 in 37500 feet. A series of basic flying quality maneuvers, Doublets, Bank to Bank Rolls and Wind-up-turns have been performed with a simulated 100% vertical tail reduction.

QUASI-TAILLESS FLIGHT DEMONSTRATION

OBJECTIVES

- **Demonstrate the feasibility of using thrust vectoring to control a directional unstable aircraft**
- **Defining required TV control power and required deflection rates**
- **Gaining experience with thrust vectoring at lower power settings**

Deutsche Aerospace

Rockwell

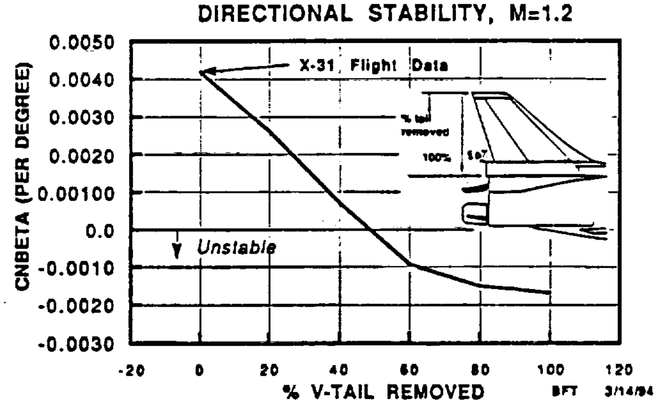
AERODYNAMIC OF TAILLESS X-31

An aerodynamic database for the reduced tail and tailless configurations was created by adding incremental (tail off - tail on) values of static and damping coefficients to the basic aero model. The basic aero was from wind tunnel data corrected by flight test Parameter Identification results. The increments were created from a combination of wind tunnel data and computed aerodynamics for tail-on and tail-reduced/off. The increments were for various percentages of tail height removed from the basic X-31 vertical tail planform.

QUASI-TAILLESS FLIGHT DEMONSTRATION

AERODYNAMIC OF TAILLESS X-31

X-31 SUPERSONIC QUASI-TAILLESS
DIRECTIONAL STABILITY, M=1.2

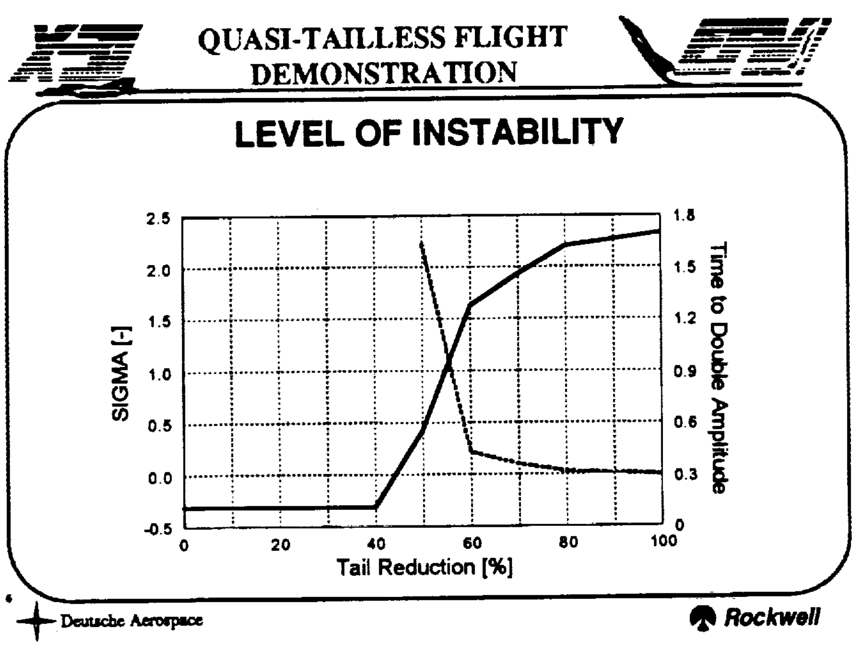


Deutsche Aerospace

Rockwell

LEVEL OF INSTABILITY

The graphic shows the level of directional destabilization, essentially the root of the dutch roll mode versus vertical tail reduction (100% is equivalent to no tail). Above 30% tail reduction the destabilized aircraft shows a positive eigenvalue. The instability increases rapidly between 30% and 70% and reaches a maximum value of 290 ms time to double amplitude at 100% tail reduction, which has been demonstrated by the X-31 at a supersonic flight condition.



QUASI-TAILLESS CONTROL LAW

Due to the unique X-31 control law design with its integrated thrust vectoring control, the quasi-tailless experiment could be performed without a major software change. The following features have been implemented. The existing augmentation via the rudder can be reduced to a desired level, or switched off completely. A destabilization feedback to rudder and ailerons has been introduced using sideslip, roll rate and yaw rate. Destabilization-gains representing different levels of destabilization (respectively tail sizes) were accessible by the pilot providing a build-up capability during the flight demonstration. A safety disengagement feature was included, that provides automatic disengagement of the quasi-tailless control mode if a system failure occurs or predetermined envelope parameters are exceeded.

QUASI-TAILLESS FLIGHT DEMONSTRATION

QUASI-TAILLESS CONTROL LAW

The following features have been implemented

- **Shutting off the existing augmentation to the rudder**
- **Introduction of a destabilization feedback to rudder and aileron**
- **Redistribution of augmentation and forward path command to thrust vectoring**
- **Additional lead-lag filter in the thrust vectoring feedback path to improve stability margins**
- **Safety disengagement if specified envelope parameters are exceeded**

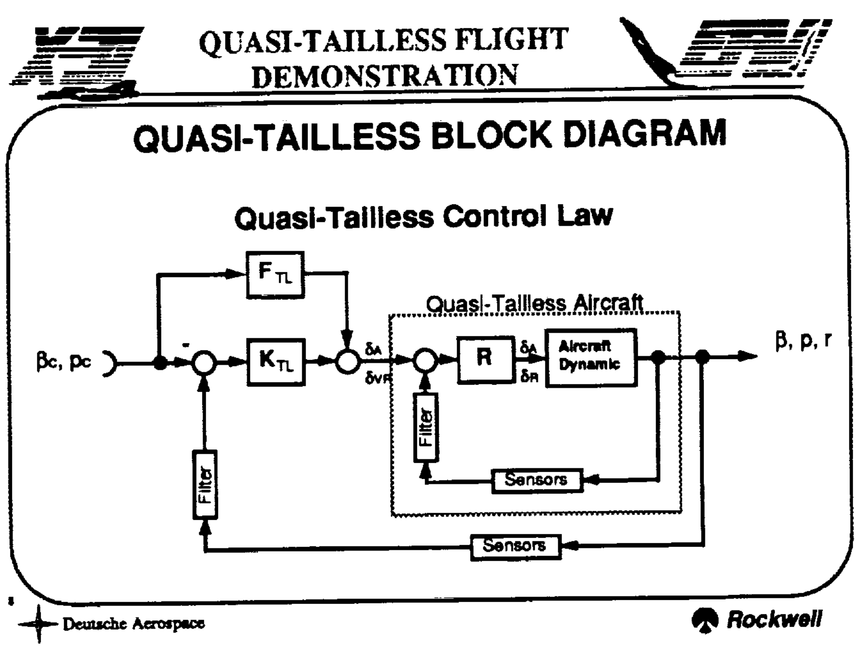
Deutsche Aerospace

Rockwell

QUASI-TAILLESS BLOCK DIAGRAM

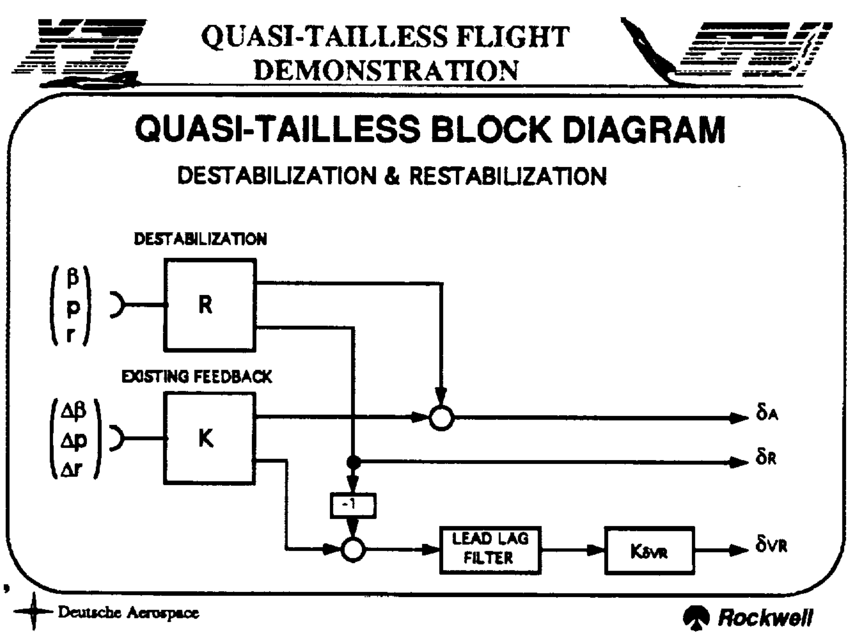
The block diagram illustrates the principle of the in-flight simulation of a tailless aircraft.

The sensed and filtered aircraft states, sideslip, roll rate and yaw rate, are fed back through a destabilization gain R to rudder and ailerons. This loop represents the quasi-tailless aircraft which is controlled by a feedback gain K_{TL} and a forward path F_{TL} using thrust vectoring and ailerons.



QUASI-TAILLESS BLOCK DIAGRAM (cont)

This block diagram shows in detail how destabilization and restabilization is mechanized.



DESTABILIZATION GAIN DESIGN

The destabilization gain matrix R is being calculated by matching the poles of the 4th order system matrix of the tailless aircraft.

Starting with matching the elements of the low order quasi-tailless system matrix (A+BR) and the tailless system matrix, the resulting gains are adjusted in order to achieve the tailless system poles with the high order quasi-tailless system.

DESTABILIZATION GAIN DESIGN

Destabilization Gain Matrix R determined by Matching the Poles of the 4th Order System Matrix of the Tailless Aircraft

$$(A + BR) \iff A_{Tailless}$$

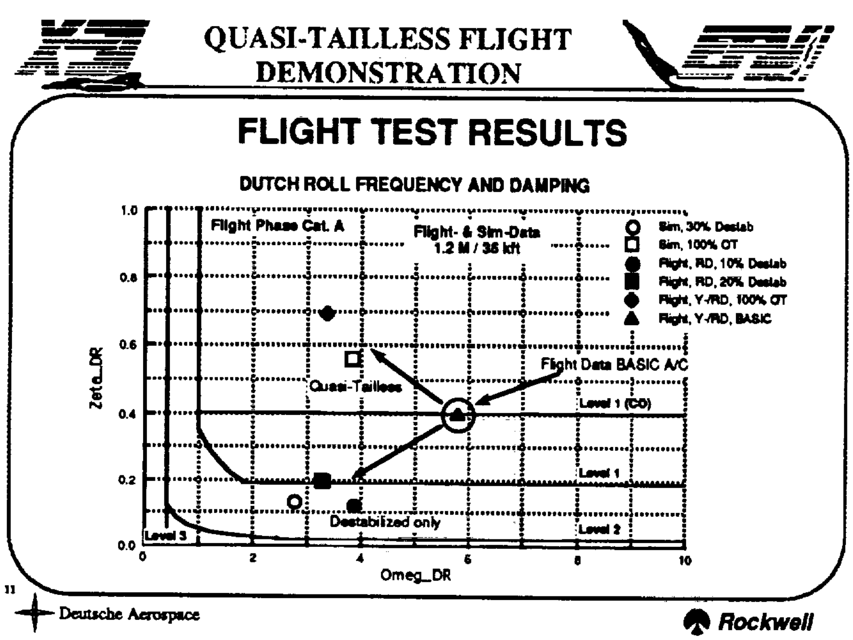
HOS LOS

FLIGHT TEST RESULTS

This diagram shows Dutch-Roll frequency and damping at the quasi-tailless demonstration flight condition evaluated via a LOES identification method. The basic X-31 has a Dutch Roll Frequency of 5.8 rad/s and a damping of 0.4.

It can be seen, that destabilization leads to lower frequency and damping values. 20% vertical tail reduction has been demonstrated in flight in the Destabilization-only Mode.

Tail reduction and restabilization via thrust vectoring leads to lower frequencies and higher damping. The Flying Qualities of the basic aircraft could not be maintained, because of an additional lead-lag filter in the thrust vectoring feedback path.

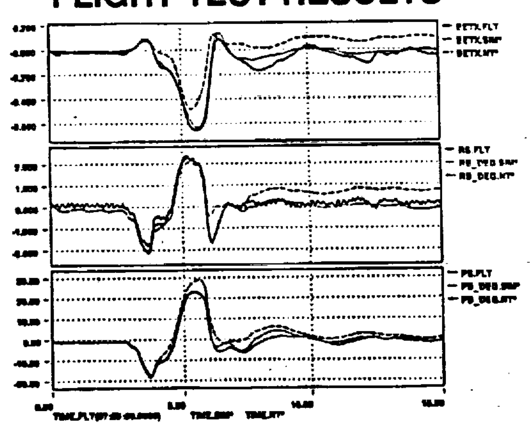


FLIGHT TEST RESULTS

Time history results of a roll doublet with 100% tail-off show excellent agreement between the quasi-tailless flight data and the non-linear quasi-tailless simulation driven by the flight pilot inputs. The rudder destabilization and thrust vectoring yaw stabilization can be seen in the first figure. The second figure adds the simulated response of the tailless X-31 (quasi tailless destabilization replaced by tailless aerodynamics model) to demonstrate the effectiveness of the quasi-tailless function in representing a tailless aircraft.

QUASI-TAILLESS FLIGHT DEMONSTRATION

FLIGHT TEST RESULTS

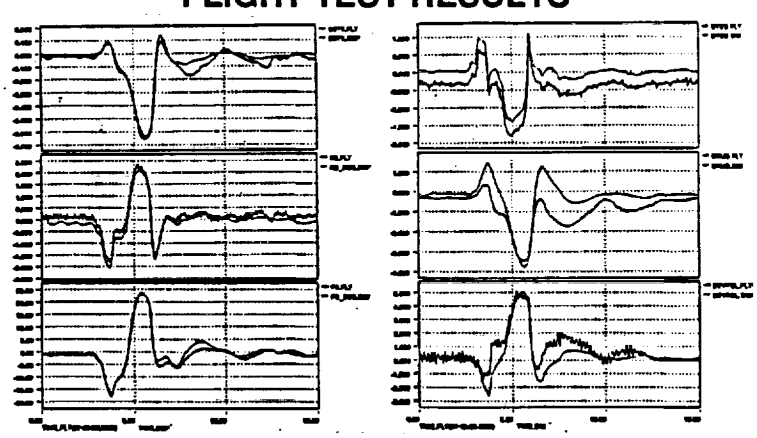


Deutsche Aerospace

Rockwell

QUASI-TAILLESS FLIGHT DEMONSTRATION

FLIGHT TEST RESULTS



Deutsche Aerospace

Rockwell

Summary

The X-31 quasi-tailless demonstration of tailless flight at supersonic speed has been a success. Flight test and supporting simulation have demonstrated that the quasi-tailless approach is effective in representing the reduced stability of tailless configurations . Destabilization to a level of almost neutral directional stability was flight tested. Quasi-Tailless destabilization/stabilization with thrust vectoring was flight tested in a build-up to a level representing complete removal of the X-31 vertical tail and rudder. The flight time histories show excellent agreement with simulation. Good correlation of quasi-tailless and a true tailless X-31 aero model in the X-31 non-linear simulation validate the concept.

The flights also demonstrated that thrust vectoring, already integrated into the X-31 flight control system for conventional and post-stall flight, could be effectively used to stabilize a directionally unstable configuration and provide control power for maneuver coordination. The X-31 program plans to continue to explore thrust vectoring stabilization and control of reduced directional stability configurations with the next flights to begin in August. The same quasi-tailless control law structure will be used with new destabilization gains to begin tests to examine different levels of directional stability and aerodynamic control at subsonic speeds. Flight conditions will vary from high subsonic cruise to landing approach. Both cruise and landing configurations will be tested to provide a more complete picture of the critical design and flight conditions for future reduced tail/tailless aircraft.

QUASI-TAILLESS FLIGHT
DEMONSTRATION

SUMMARY

- **Quasi-Tailless Approach Is Effective In Representing Reduced Stability of Tailless Configurations**
  - **Destabilization Up to 30% Tail Removed Has Been Flight-Demonstrated**
  - **Quasi-Tailless Up to 100% Tail-off Has Been Flight-Demonstrated**
  - **Simulation of Quasi-Tailless Matches Tailless Configuration**
- **Thrust Vectoring Effective In Stabilizing and Providing Maneuver Coordination For Directionally Unstable Configuration at Supersonic Speeds.**
- **Flight Test and Analysis Will Continue With X-31 Subsonic Quasi-Tailless**
  - **Subsonic Cruise Down to Landing Speeds**
  - **Cruise and Landing Configurations**
  - **Next Flights With New Destabilization Gains Planned for August**

Deutsche Aerospace Rockwell