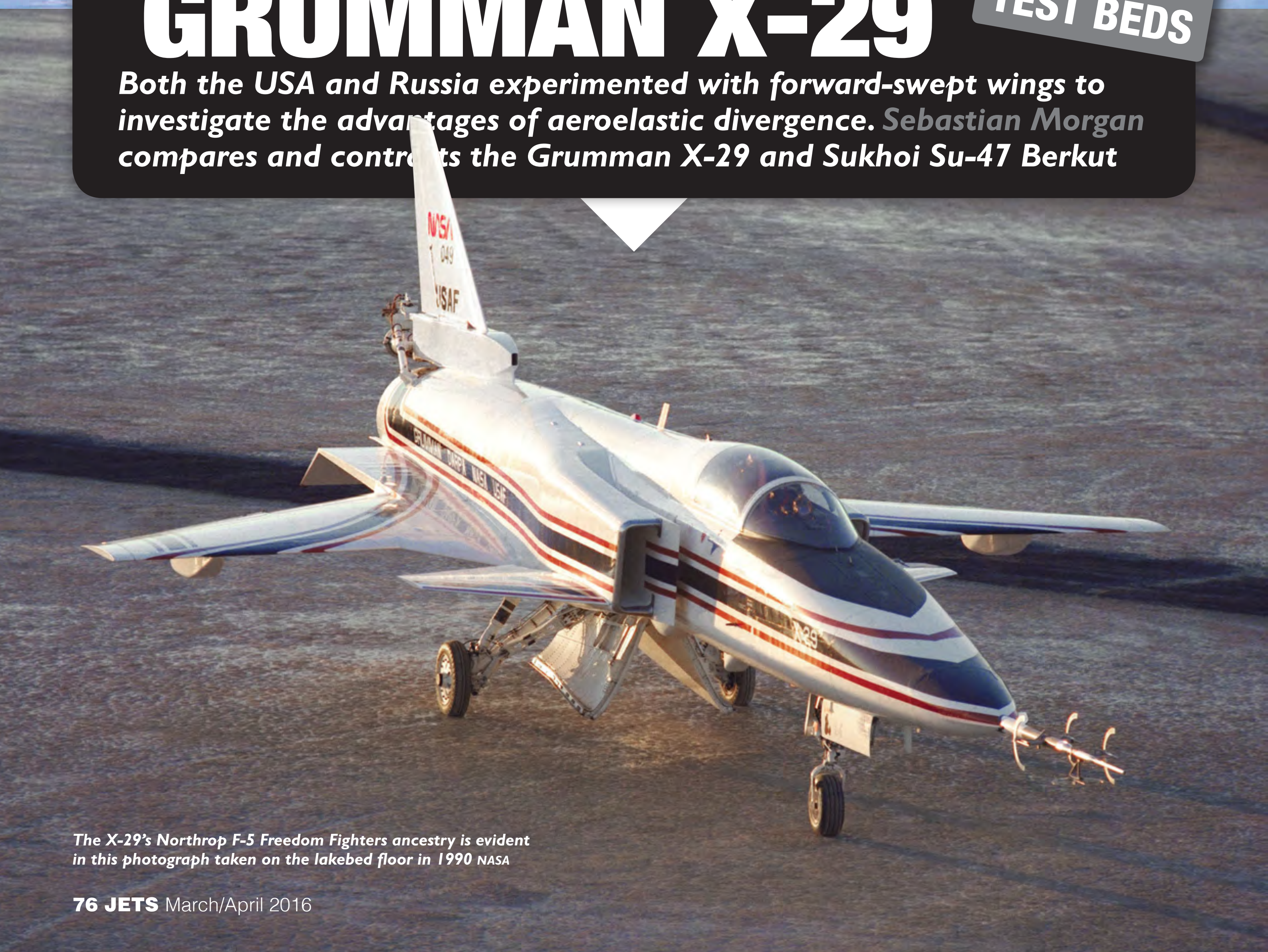
Striking a dramatic pose, the first of two Su-47 Berkuts peels away from the camera during a sortie for the company photographer Sukhoi Design Bureau

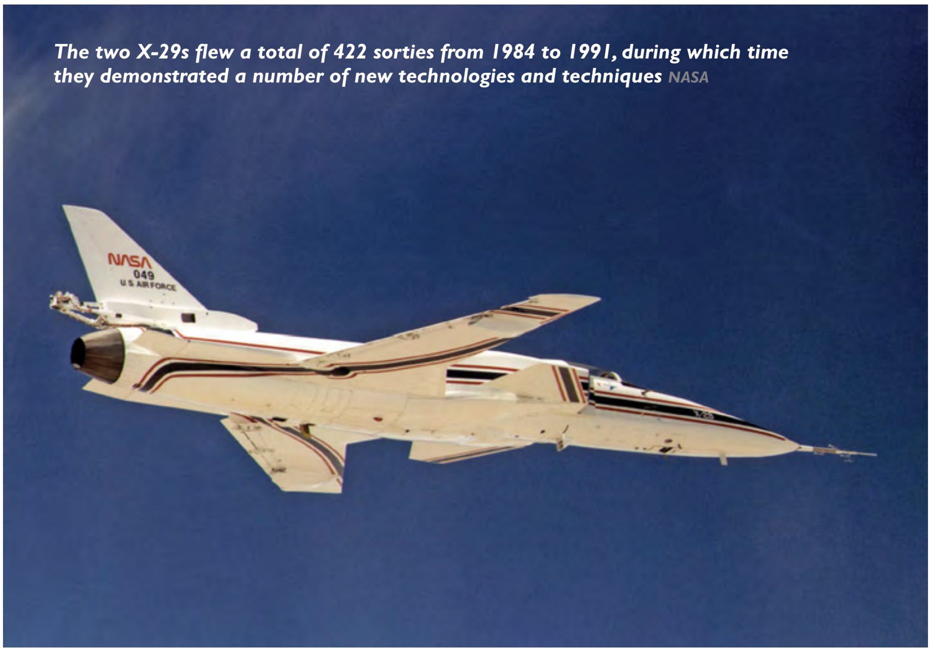
SUKHOI SU-47 VS GRUMMAN X-29

FORWARD-SWEPT TEST BEDS

Both the USA and Russia experimented with forward-swept wings to investigate the advantages of aeroelastic divergence. Sebastian Morgan compares and contrasts the Grumman X-29 and Sukhoi Su-47 Berkut



The X-29's Northrop F-5 Freedom Fighters ancestry is evident in this photograph taken on the lakebed floor in 1990 NASA



The two X-29s flew a total of 422 sorties from 1984 to 1991, during which time they demonstrated a number of new technologies and techniques NASA

The second X-29 (complete with anti-spin 'chute fairing on the tail) conducts high angle of attack testing with smoke generators NASA

In the quest to create the next generation of highly manoeuvrable fighter jets, attention turned in the 1980s towards an aircraft with a forward-swept wing configuration.

It was thought that having a conventional wing – albeit mounted with the sweep towards the front of the aircraft – as well as canard foreplanes would result in exceptional manoeuvrability, supersonic performance and a light structure.

Forward-swept wings yield a higher maximum lift coefficient and delayed stall when compared to more traditional wing shapes. Wind tunnel testing showed that air moving over the forward-swept wings tended to flow inward towards the root of the wing instead of outward towards the wing tip, as occurs on 'conventionally' swept wing. This reverse airflow keeps the wingtips and their ailerons from stalling at high angles of attack and enables the aircraft to be controlled at much slower speeds or severe angles of flight.

Aerolastic divergence

However, this so-called 'aeroelastic divergence' also causes a twisting force which rotates the wing leading edge upward. This results in a higher angle of attack, which increases lift but also twists the wing further. Aeroelastic divergence can quickly lead to structural failure in a conventional metal winged aircraft.

The forward-swept wing concept was investigated, to a limited level, by gliders in the pre-war years and the National Advisory Committee for Aeronautics (NACA) Langley Memorial Aeronautical Laboratory in Hampton, Virginia, performed wind-tunnel studies on the concept in 1931.

During World War Two, Germany also developed the jet-powered Junkers Ju 287 with forward-swept wings; however, the concept was unsuccessful as the technologies and materials to construct a wing rigid enough to overcome the bending and twisting forces did not exist.

In the 1960s Hamburger Flugzuebau created the Hansa Jet HFB-320 business jet, and to date this remains the only civilian aircraft certified with a forward-swept-wing. However, the performance of the HFB-320 was certainly not fighter-like and it was felt that the introduction of composite materials in the 1970s opened a new field of aircraft construction, making it possible to design a rugged fighter jet with structures stronger than those made of conventional materials, yet lightweight and able to withstand tremendous aerodynamic forces.

In 1977 the American Defense Advanced Research Projects Agency (DARPA) and the USAF Flight Dynamics Laboratory at Wright-Patterson Air Force Base, Ohio, issued proposals for a research aircraft designed to explore the forward-swept wing concept. The aircraft was also intended to validate studies that predicted better control and lift qualities in extreme manoeuvres and possibly reduce aerodynamic drag, as well as fly more efficiently at cruise speeds.

> "The fly-by-wire system adjusted the control surfaces with up to 40 commands each second"

In December 1981, the Grumman Corporation's bid was deemed successful and the company received an $87 million contract to build the first new X-series aircraft in more than a decade.

Supercritical

Research suggested that the configuration of forward-swept wings coupled with movable canards would give pilots excellent control response at up to 45 degrees angle of attack,

Viewed from above, the first X-29 demonstrates the forward-swept wing to great effect NASA

The X-29 cockpit borrowed much from the Northrop F-5 Freedom Fighter from which it was developed NASA

"The X-29 became the first forward-swept wing aircraft to fly at supersonic speed in level flight"

The first X-29 to fly was 82-003, which performed its maiden flight on December 14, 1984 USAF Museum

An in-flight close-up of the anti-spin 'chute fairing on the tail of the second X-29 NASA

higher than comparable fighter aircraft. Grumman's fighter-sized X-29 was created to explore the concept and would also investigate advanced construction techniques, variable camber wing surfaces, a thin supercritical airfoil, strake flaps, close-coupled canards and a highly-advanced computerised fly-by-wire flight control system.

Conventionally configured aircraft achieve stability by balancing lift loads on the wing with opposing downward loads on the tail at the cost of drag. The X-29 avoided this drag penalty through its reduced static stability and aft centre of gravity. The fly-by-wire system compensated for this instability by continually adjusting the control surfaces with up to 40 commands each second.

The very thin supercritical wing was built of state-of-the-art composites that featured 'aeroelastic tailoring' to allow the wing to bend (within limits) but not deform or break off in flight.

The wing was also fitted with flaperons (combined flaps and ailerons) to change wing camber and function as ailerons for roll control when used asymmetrically. In addition, the strake flaps on each side of the rudder augmented the canards with pitch control. The control surfaces were linked electronically to a triple-redundant digital fly-by-wire flight control system that provided an artificial stability.

The two X-29 test beds were built by Grumman from the shells of a pair of existing Northrop F-5A Freedom Fighter airframes (63-8372 became 82-0003 and 65-10573 became 82-0049). To save costs the experimental jets used the forward fuselage and nose landing gear from the F-5As with the control surface actuators and main landing gear from the General Dynamics F-16.

"An aircraft with extreme instability could still provide good handling qualities"

Mated to the 'conventional' airframe were the 27ft 2in span carbon fibre/graphite epoxy wings that were swept forward by more than 33 degrees. The aircraft weighed in at 13,800lbs empty and was designed with a maximum take-off weight of 17,800lbs.

Test flights

Dubbed internally as the 'Model 712', the first X-29 was ready to perform its maiden flight by late 1989 and on December 14, Grumman's Chief Test Pilot Chuck Sewell took the jet aloft from Edwards AFB in California.

The X-29 began a NASA test programme four months after its maiden flight and almost exactly a year later, on December 13, 1985, the X-29 became the first forward-swept wing aircraft to fly at supersonic speed in level flight. This was later increased to Mach 1.6.

By August 1986 the X-29 was flying research missions of over three hours and the second airframe – which first flew on May 23, 1989 -- was soon specialising in high angle-of-attack testing. The airframe was found to be perfectly manoeuvrable up to an angle of attack of about 25 degrees with a maximum angle of 67 degrees reached in a momentary pitch-up manoeuvre.

The two X-29s flew a combined total of 422 sorties from 1984 to 1991, and a further 60 flights were completed in a follow-on 'vortex control' study.

Although the project was deemed to be

In this image a number of 'tufts' have been placed on the wings and fuselage of the second X-29 to allow high definition cameras to analyse the airflow across the airframe at high angles of attack NASA - Larry Sammons

The first prototype Su-47 Berkut taxies out at Zhukovsky in 1999 for a flight test sortie **Viktor Drushlyakov**

a success, the X-29 did not demonstrate the overall reduction in aerodynamic drag that earlier studies had suggested. Nonetheless, the programme demonstrated several new technologies including aeroelastic tailoring to control structural divergence and use of a relatively large, close-coupled canard for longitudinal control.

The programme also proved that an aircraft with extreme instability could still provide good handling qualities and demonstrated the use of vortex control and double-hinged trailing-edge flaperons at supersonic speeds for the first time.

Today the first X-29 (82-003) is on display in the Research and Development Gallery at the National Museum of the USAF in Dayton, Ohio and the second aircraft can be seen at the Armstrong Flight Research Center at Edwards AFB.

The X-29 is arguably one of the most unusual and beautiful aircraft ever to fly **NASA**

Sukhoi's 'Golden Eagle'

Although the USA is believed to have abandoned the forward-swept wing idea in the early 1990s, Russian engineers continued to explore the concept for some time.

The Tsentralniy Aerogidrodinamicheskiy Institut (Central Aerohydrodynamic Institute) had long been aware of the advantages of forward-swept wings and had extensively studied and test-flown the captured Junkers Ju 287 at the end of World War Two. So when the Soviet Air Force issued a 1983 order to evaluate the concept, the knowledge was passed to the Sukhoi Design Bureau for incorporation into a flying test-bed.

waterborne targets, including small size and mobile targets. As such the aircraft would need to be fitted with an integrated armament system.

Design studies were completed by 1988 – the use of canards and an all-moving tailplane (the so-called tandem triplane concept) already proven on a Sukhoi Su-27 *Flanker*.

Throughout the early 1990s the aircraft continued to take shape and was originally announced as the Su-32, although this was later changed to Su-37 and finally re-designated as the Su-47 in 2001.

Other than its physical size, the most obvious difference from the X-29 was the Russian aircraft's twin tailfins; something it shared with other Sukhoi jet fighters of the era such as the Su-35 *Flanker*. In fact,

> "The aerodynamic layout would reduce radar signature"

Although similar in overall concept to X-29, the Russian research aircraft was about twice the size and far closer to an actual combat aircraft than the US design.

Designed as a proof of concept aircraft for 'fifth generation fighter' technologies, the aircraft was optimised with the best aerodynamic layout to provide an improvement in manoeuvrability, a reduction in its radar signature and also give a prolonged cruising supersonic flight capability.

The new Russian aircraft would be required to strike ground-based and

the airframe also shared the nose, forward fuselage, undercarriage and canopy from the Su-35.

Like the X-29, the Su-37 boasted large canards mounted on the forward fuselage. Power came from a pair of Soloviev D-30F6 turbofans producing 34,172lb/thrust each in full reheat. The engines were also capable of thrust vectoring with 20 degrees of lateral movement at 30 degrees per second.

Sukhoi christened the new aircraft the Berkut (Golden Eagle) but the Su-37 was unkindly given the NATO reporting name *Firkin*.

Unlike the X-29, the Su-47 was designed from the outset to be an armed fighter, as demonstrated by the prototype's weapons bay Viktor Drushlyakov

Stalled

Work moved at a rapid rate and the prototype was expected to perform its maiden flight in 1991, quickly followed by a production version five years later to counter the USAF's Advanced Tactical Fighter (ATF) programme (which would ultimately lead to the F-22 Raptor).

However, the increasing economic crisis in the USSR and the subsequent disintegration of the Soviet Union resulted in significant defence budget cuts and the Berkut was one of the first casualties. Sukhoi drew on its own funds to continue development – albeit at a much reduced pace.

The prototype's fuselage was eventually completed in mid-1996 and static testing began in May 1997. Two months later the prototype was shipped to Zhukovsky airfield near Moscow for further testing and the aircraft eventually took to the skies on September 25, 1997.

Eight flights had been conducted by the end of November and Sukhoi officials reported the programme to be performing well. In 1999 the Su-37 was officially recognised by Russia as an experimental aeroplane and prototype, and official flight-testing began.

Around the same time the Su-37 was re-engined with Aviadvigatel D-30F11 turbofans – each producing 32,000lb/thrust in full reheat – taken from the Mikoyan Gurevitch MiG-31 *Foxhound*. With this engine the Berkut could reach supersonic speed and supercruise without afterburners.

> "Sukhoi christened the new aircraft the Berkut (Golden Eagle)"

In 2001 the aircraft was re-designated as the Su-47 and officially unveiled to the world at that year's MAKS Airshow at Zhukovsky.

The Su-47 demonstrated extremely high agility at subsonic speeds, enabling the aircraft to alter its angle of attack and its flight path very quickly. Reports from test pilots also referred to remarkable supersonic manoeuvrability, a 9G capability and a maximum speed of Mach 1.6.

Flight-testing continued and in April 2002

The Berkut is photographed here high above the Zhukovsky airfield from which it has conducted much of its flight-testing Sukhoi Design Bureau

Flying low over the Russian countryside, the Su-47 is an unmistakable aircraft Sukhoi Design Bureau

Trailing wingtip vortices, the first Berkut manoeuvres at altitude Sukhoi Design Bureau

The Su-47 shared its tailfins and forward fuselage with the existing Su-27 and Su-35 Flanker family Sukhoi Design Bureau

Seen landing back at Zhukovsky during an early test flight the Su-47 demonstrates the undercarriage it shares with the Flanker family of Sukhoi jets Viktor Drushlyakov

Looking like an extra from Star Wars, *the Su-47 flies off into the sunset during a test flight* Sukhoi Design Bureau

SPECIFICATION
GRUMMAN X-29

Artwork: Andy Hay / www.flyingart.co.uk

Crew	1
Length	48ft 1in (14.70m)
Height	14ft 9in (4.26m)
Wingspan	27ft 2in (8.29m)
Wing Area	189sq ft (17.54m2)
Empty Weight	13,800lb (6,260kg)
Max Take-Off Weight	17,800lb (8,070kg)
Max Speed	956kts (1,100mph / 1,770km/h / Mach 1.8)
Service Ceiling	55,000ft (16,800m)
Ferry Range	350 miles (560km)

Powerplant One General Electric F404 turbofan (16,000lb/thrust)

First Flight December 14, 1984

SPECIFICATION
SUKHOI SU-47 BERKUT

Artwork: Andy Hay / www.flyingart.co.uk

Crew	1
Length	74ft 2in (22.60m)
Height	20ft 8in (6.30m)
Wingspan	54ft 9in (16.70m)
Wing Area	666sq ft (61.87m2)
Empty Weight	36,100lb (16,375kg)
Max Take-Off Weight	77,162lb (35,000kg)
Max Speed	926kts (1,066mph / 1,717km/h / Mach 1.65)
Service Ceiling	59,050ft (18,000m)
Ferry Range	2,050 miles (3,300km)

Powerplant Two Aviadvigatel D-30F11 thrust vectoring turbofans (32,000lb/ thrust with reheat)

First Flight September 25, 1997

> "Test pilots reported 9G capability and a maximum speed of Mach 1.6"

the Sukhoi Design Bureau was chosen to lead a team developing a new, fifth-generation, combat aircraft dubbed the T-50. Although significantly more 'conventional' looking than the Su-47 – and lacking the forward-swept wing – the T-50 [also referred to as the PAK-FA] utilised much of the development work undertaken by the Berkut and first flew in January 2010.

Since then it has been generally assumed that the Su-47 programme had been halted. However, on August 11, 2014 the Commander-in-chief of the Russian Air Force, Colonel General Viktor Bondarev claimed that Russia is still continuing the research and development with two Su-47 "or similar forward-swept wing fighters." He claimed that the new prototypes of such aircraft would be unveiled in the near future…The world waits with baited breath. ●