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R&D Activities for Aeronautics S&T in Japan, the United States and Europe

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1 Introduction

The YS-11 twin-engine, turboprop small passenger plane was developed in the late 1950s to the early 1960s as the first Japanese-developed passenger aircraft since the end of World War II. However, a decision to halt its production was made in December 1971[1,2] because of weak sales and huge losses. A total of 182 YS-11 units were manufactured before the production was halted in 1974, and the last of them retired from commercial airline service on September 30, 2006. After the development of YS-11, there were no national projects to develop civil aircraft until the late 1990s.

Although Japan is internationally competitive with regard to household electric appliances, electronics equipment and transport equipment such as cars, railways and vessels, Japanese industry's role in civil aircraft manufacturing has been limited as a supplier of subsystems and components of airframes and engines in international development projects with U.S. and European aircraft manufacturers.[1] Since the beginning of this century, Honda Motor Co. and Mitsubishi Heavy Industries Ltd. (MHI) have announced plans to enter the civil aircraft market, through a small business jet called HondaJet in the case of Honda, and a small passenger jetliner called the Mitsubishi Regional Jet (MRJ) in the case of (MHI). The market for medium- and large-size passenger aircraft with a passenger capacity of 100 or more and with a flying range of more than 5,000 kilometers is dominated by the duopoly of Boeing Co. of the United States and Airbus of Europe. The market for regional jets with a passenger capacity of around 100 and a flying range of a few thousand kilometers is controlled by Bombardier of Canada and Embraer of Brazil, while Sukhoi of Russia, with its SSJ jet, and Commercial Aircraft Corporation of China Ltd., with its ARJ21, as well as Mitsubishi Heavy Industries Ltd, with its MRJ, are planning to enter this market.[3] The MRJ's entry into the market will be far from easy. There is an argument stating that as Japan lacks total aircraft integration technology, it is necessary for all parties involved in the Japanese aeronautical sector to work together to promote the development of the MRJ.[4] We hope that the development of the MRJ and HondaJet will help to foster the international competitiveness of Japan's aeronautical industry.

This report first describes global warming-related developments, which have been a recent focus of attention, in relation to aeronautical technology. It then studies how Japan should promote R&D programs in the future based on the investigation and analysis of environmental R&D programs in Japan, the United States and Europe that aim to develop environment-friendly aircraft with reduced greenhouse gas emissions and noise levels, for example.

2 Global Warming-related Developments

As shown in Figure 1, a jet engine emits a variety of gases and substances generated as a result of the high-temperature, high-pressure combustion of compressed air and fuel.[5] The Intergovernmental Panel on Climate Change, which was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Programmed (UNEP), issued a special report on the

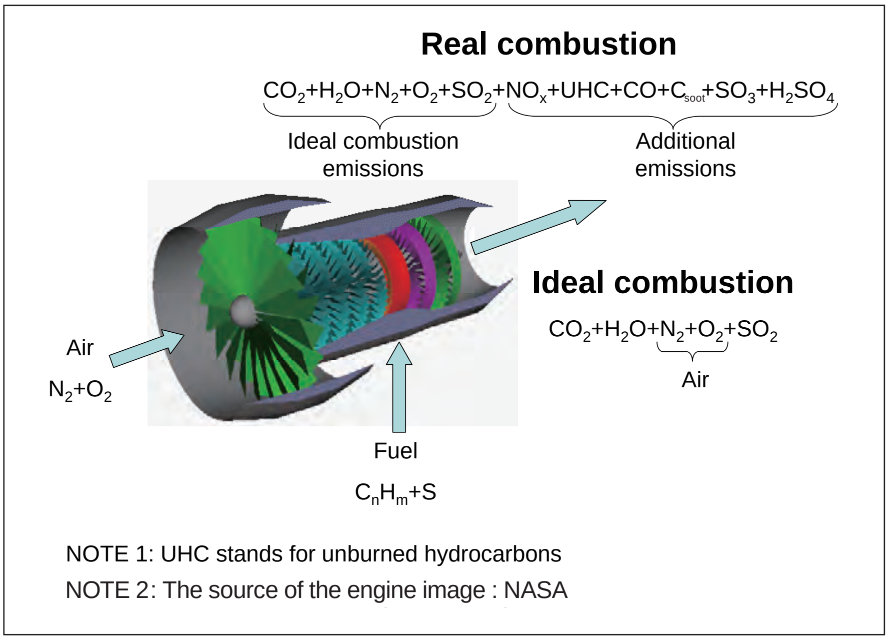


Figure 1 : Ideal and real combustion processes for jet engines

Source: Reference[5]

impact of aircraft emissions on global warming in 1999 in response to a request from the International Civil Aviation Organization (ICAO).[6]

As shown in Table 1, major climate-influencing factors include carbon dioxide (CO_2), which is a major greenhouse gas; nitrogen oxides (NO_X), which generate tropospheric ozone and reduce methane; and water vapor (H_2O) which leads to the formation of contrails and cirrus clouds; and soot and aerosol particles.[7] It should be noted that the combustion of 1kg of fuel emits 3,160g of CO_2, 1,290g of H_2O, up to 15g of nitrogen oxides and up to 1g of other gases and substances.[8]

Regarding the global warming effects of aircraft emissions, the radioactive forcing of contrails is estimated at 0.02W/m^2, while a range of 0 to 0.04 W/m^2 is estimated for cirrus clouds as there are factors that are not well understood. Radiative forcing is an index that expresses a change in the energy equilibrium between the ground surface and atmosphere due to changes in various factors, including changes in the concentration of greenhouse gases, as the rate of energy change per unit area at the tropopause, which represents the atmospheric boundary between the troposphere and the stratosphere. Radioactive forcing is expressed as a positive figure when it has the effect of warming the ground surface and as a negative figure when it has the effect of cooling it.[9] IPCC's fourth report, issued in 2007, evaluated the impact of aviation on global warming.[10] The report estimated that the amount of CO_2 emissions from global aviation increased by a factor of 1.5, to approximately 480MtCO_2 in 2000 from approximately 330MtCO_2 in 1990, accounting for around 2% of overall anthropogenic CO_2 emissions. The report warned that in the absence of additional measures, projected annual improvements in aircraft fuel efficiency of the order of 1–2% will be largely surpassed by traffic growth of around 5% each year, leading to a projected increase in emissions of 3–4% per year. The report estimated the radiative forcing of contrails at approximately 0.01W/m^2, about half the level estimated in the special report issued in 1999 (although as a figure for 1992). This discrepancy is attributable to an improvement in satellite-based cloud observation technology and an advance in studies on cloud radiative forcing. Meanwhile, the report did not provide an assessment of the radiative forcing of cirrus clouds on the grounds that relevant mechanisms are not well understood by modern science. It should be noted that various evaluation results have been published with regard to the impact of cirrus clouds on global warming.[11]

Under the Kyoto Protocol, international aviation, unlike domestic aviation, is not included among the sectors/source categories listed in Annex A. Therefore, greenhouse gas emissions resulting from international aviation are not subject to the obligation for the limitation or reduction of

Table 1 : Climate Change Impacts of Aviation Emissions

Climate Effect	Nature of Impact	Scientific Understanding
CO_2 generation	• Lasts in the atmosphere for dozens or hundreds of years or even up to thousands of years • Has the same impact wherever it is emitted. • The effect is global.	"Good" There is widespread acceptance that research has provided a robust understanding of the scale and climate impacts of aviation-related CO_2.
Tropospheric ozone generation	• Emissions of NO_X during cruising generate tropospheric ozone (which can cause climate warming). The extent of the ozone effect also depends on altitude, location and atmospheric conditions. • The lifetime of ozone is several weeks. • The warming effects are regional rather than global.	"Fair" There is uncertainty over the extent of the impact. The IPCC notes that changes in tropospheric ozone levels are mainly in the Northern Hemisphere, while those of methane are global in extent. Given this, the net regional radiative effects do not cancel.
Methane reduction	• Emissions of NO_X result in the reduction of ambient levels of methane (from other sources) in the atmosphere, which results in cooling. • The lifetime is around 8-12 years. • The effects are global.	
Contrails and cirrus cloud formation	• Contrails only form at altitude in very cold, humid atmospheric conditions. Ambient temperature and the level of ice-supersaturation regulate the lifetime of a contrail, which may vary from seconds to hours. Contrails may in turn lead to the formation of cirrus clouds. • The warming effects are highly dependent on altitude, location and atmospheric conditions. The extent of enhanced cirrus that arises from aircraft contrails and particle emissions is not well quantified, although there is some evidence of a correlation between cirrus trends and air traffic.	"Fair" for contrails, but "poor" for cirrus clouds Generally, the role of clouds, including cirrus, in climate change is one of the least understood aspects.
Soot and aerosols	• Effects are more pronounced at altitude than at ground level. • Soot traps outgoing infrared radiation and has a small warming effect. • Sulphate aerosols reflect solar radiation and have a cooling effect. • The lifetime of both is brief. The effects are regional.	Understanding is "Fair"

Source: Reference[7]

greenhouse gas emissions by the parties to the protocol that are listed in Annex I, and so such emissions are not automatically covered by emissions trading as defined under Article 17 of the Kyoto Protocol.[12] However, Article 2.2 stipulates that, "The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases" resulting from aviation, working through the International Civil Aviation Organization (ICAO). In light of this, ICAO is considering the establishment of a governmental or private-sector emissions trading system. It should be noted that ICAO's Committee on Aviation Environmental Protection (CAEP) set standards for the emissions of gases harmful to humans, such as carbon monoxide (CO), hydrocarbons (HCs) and nitrogen oxides (NO_X) during the landing-takeoff (LTO) cycle as well as for noise levels, and these standards have been strengthened over time.

On January 1, 2005, the European Union launched the EU Emission Trading Scheme (EU-ETS), which handles emissions of CO_2, one of the greenhouse gases listed in the Kyoto Protocol. The EU-ETS completed the first phase, which was regarded as a trial period, at the end of 2007, and it is now in the second phase, which spans the period between January 2008 and the end of 2012, coinciding with the commitment period under the Kyoto Protocol.

The European Commission, looking beyond the Kyoto Protocol, has strengthened European efforts to fight against global warming and proposed to (1) reduce the amount of greenhouse gas emissions by 20% (by 30% if an international agreement is reached) by 2020 compared with 1990 and (2) set an EU-wide emissions cap, rather than caps for individual EU member states, in order to reach the EU target of a 20% share of renewable energy in overall energy consumption by 2020 and include allowances for the emissions of greenhouse gases other than CO_2 in the EU-ETS. After undergoing some revisions, this proposal was approved in December 2008 by the European Council and the European Parliament.[13] As a result of the approval, starting in 2012, greenhouse gas emissions from flights arriving in and taking off from airports in the EU region are expected to be covered by the EU-ETS regardless of whether the flights are intra-EU ones or not.[14,15] Commercial air carriers, but not the government agencies of the EU states, will be in principle subject to the regulation, with each carrier administered by the supervisory body of one member state. However, carriers based in countries that take measures similar to the EU approach may be exempted from the regulation. Only CO_2 emissions will be subject to the regulation. For each carrier, the baseline emissions amount will be calculated in accordance with the revenue-ton-kilometers (passengers and cargo expressed in weight multiplied by the distance flown) based on the annual average of overall emissions from its flights arriving at and taking off from airports in the EU region. Aviation emissions will be capped at 97% of the emissions amount thus calculated in 2012 and at 95% between 2013 and 2020. Each carrier will be allotted 85% of the cap for free, with the remaining 15% to be auctioned. To simplify procedures, operators of small aircraft will be excluded from the EU-ETS.

According to Sustainable Aviation, a U.K. environmental organization, the amount of CO_2 emissions from U.K. air transportation in Britain will increase by a factor of around three by 2050 compared with 2000 on the assumption of no improvement in technology (at constant technology level).[16] On the assumption of air traffic management improvements, the development of advanced technologies related to the Air Transportation System (ATS) based on the Strategic Research Agenda set by the Advisory Council for Aeronautics Research in Europe (ACARE) and low-carbon alternative fuels as well as post-ACARE ATS technologies, Sustainable Aviation estimates that CO_2 emissions will peak around 2020 and could be reduced to 2000 levels by around 2050. As the EU-ETS is expected to be applied in principle to emissions from commercial flights arriving at and

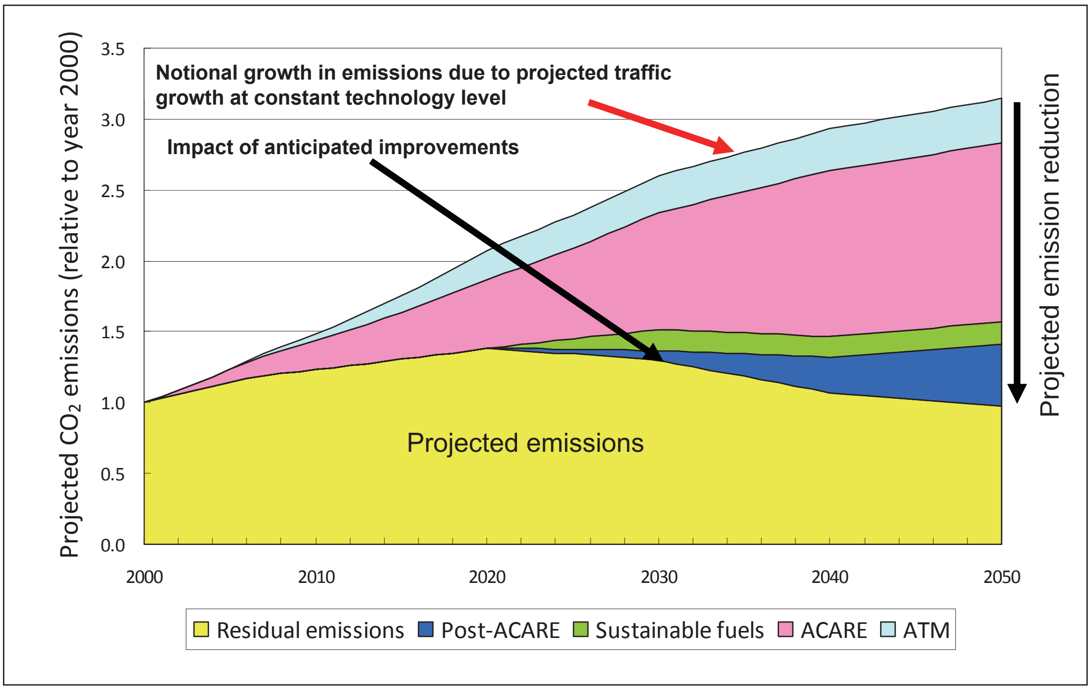


Figure 2 : Projected future emissions of CO_2 from U.K. aviation (relative to year 2000)

Source: Reference[16]

taking off from airports in the EU region starting in 2012, demand for environment-friendly aircraft with significantly reduced emissions of CO_2 and other greenhouse gases is likely to grow in the future.

3 R&D Activities in Japan and Abroad

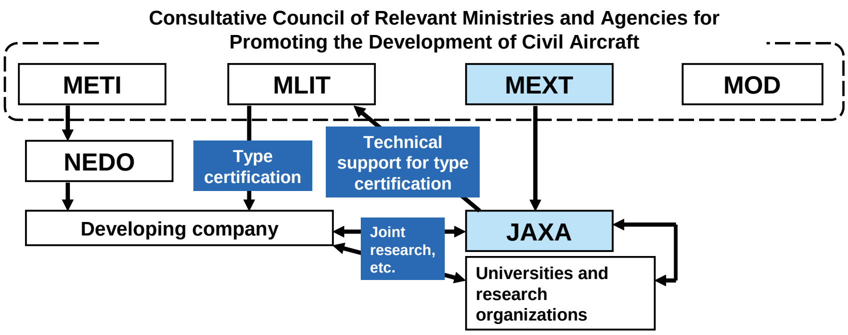
3-1 Japan

The Sector-by-Sector Promotion Strategy,[17] which was adopted on March 28, 2006, by the Council for Science and Technology Policy based on the 3rd Science and Technology Basic Plan, has seleted “domestic aircraft technologies that meet new demand” and “new preventive safety technologies related to traffic and transportation” as priority strategic technologies that require intensive investment, citing both as technologies for adapting to new society within the traffic and transportation system technologies that suit new society in the field of social infrastructure. The technical scope of the domestic aircraft technologies that meet new demand is specified as “prototype development and corresponding technology development selected from the total aircraft integration technologies that could realize aircraft and engines meeting new demands, R&D for quiet supersonic experimental aircraft, and inventions of, and processing technologies for, composite materials that maintain and strengthen Japan’s international competitiveness.” As for the reason for selecting these technologies, the strategy states that because “it is essential for Japan to secure its unique domestic technical capabilities that it has so far acquired through its participation in international join development projects, strategic priorities shall be placed on the total aircraft integration technologies and the improvement of supporting element technologies…(and) the technologies… for meeting future higher speed needs.” The scope of new preventive traffic and transportation safety technologies is specified as “IT-based air traffic management technologies, including four-dimensional (three dimensions in space and one dimension in time) traffic management that will enable safe high-density flights, flight support technologies for small aircraft and all-weather, high density flight technologies.” The reason given for selecting these technologies is that “with due consideration of future growth in air traffic demand, it is necessary to place priorities on promoting the use of new technologies necessary for ensuring preventive safety.”

(1) Total Aircraft Integration Technologies

With regard to the total aircraft and engine integration, which is included among domestic aircraft technologies that meet new demand, the Research and Development of Environment-Friendly, High-Performance Small Aircraft[18] and the Research and Development of Environment-Friendly Small Aircraft Engine (the Eco Engine Project)[19] have been underway since fiscal 2003 as projects managed by the New Energy and Industrial Technology Development Organization (NEDO), which is under the jurisdiction of the Ministry Economy, Trade and Industry (METI). The outline of the framework for the implementation of these projects is as described in Figure 3.[20,21]

The Japan Aerospace Exploration Agency (JAXA), one of whose supervising government ministries is the Ministry of Education, Culture, Sports, Science and Technology (MEXT), stated, under its first mid-term plan (October 1, 2003 to March 31, 2008), that it was its goal to “participate as joint research activities in, as well as provide active technical assistance and access to large facilities to” the Research and Development of Environment-Friendly, High-Performance Small Aircraft project and the Research and Development of Environment-Friendly Small Aircraft Engine project.” Furthermore, under its second mid-tem plan (April 1, 2008 to March 31, 2013), it states that it is its goal that “JAXA will conduct advanced and fundamental aeronautical science and technology R&D activities focused on strategically prioritized S&T provided for in the third Science and Technology Basic Plan. Specifically, JAXA will conduct highly value-added and technically differentiating R&D activities for high performance indigenous passenger aircraft and the Clean Engine as R&D activities contributing to aircraft and engine advancement.” JAXA, pursuant to the above stated goals, has been conducting advanced R&D activities such as the “Clean Engine” project that will develop by around 2012 an engine whose goal is to be more environment-friendly than the Eco Engine, which will be developed by around 2010, and the “High Performance Indigenous Aircraft”



Project Name	JAXA, universities and research organizations (roles)
Research and Development of Environment-Friendly, High-Performance Small Aircraft	• JAXA (Joint research with the developing company: Development and evaluation of advanced aerodynamic design technology, evaluation of advanced materials and processing and molding technologies, cockpit evaluation, evaluation of control systems.) • Tohoku University (Joint research with the developing company: Aerodynamic analysis and development of airframe configuration design technology)
Research and Development of Environment-Friendly Small Aircraft Engine	• JAXA (Transfer of technology with high value added to the developing company, support for design and development, joint research concerning the "eco-engine" and the "clean engine" with the developing company, implementation of development tests on behalf of the developing company) • National Institute for Materials Science, Tohoku University, Tokyo University of Agriculture and Technology and Waseda University (Joint research with the developing company concerning the "eco-engine" and the "clean engine"
NOTE: Type certification is under consideration with regard to the Research and Development of Environment-Friendly, High-Performance Small Aircraft project.	

Figure 3 : Outline of the Framework of NEDO's Project Implementation

Source: Reference[18~21]

whose goal is to further reduce noise and improve fuel efficiency, safety and passenger comfort as well as technically assisting these NEDO projects. In addition, it has provided its wind tunnel testing and computational fluid dynamics (CFD) facilities, which are among the largest such facilities in Japan, for use in these projects, and it also plans to build a jet flying test bed (FTB), which enables operating-environment assessment of equipment.[24]

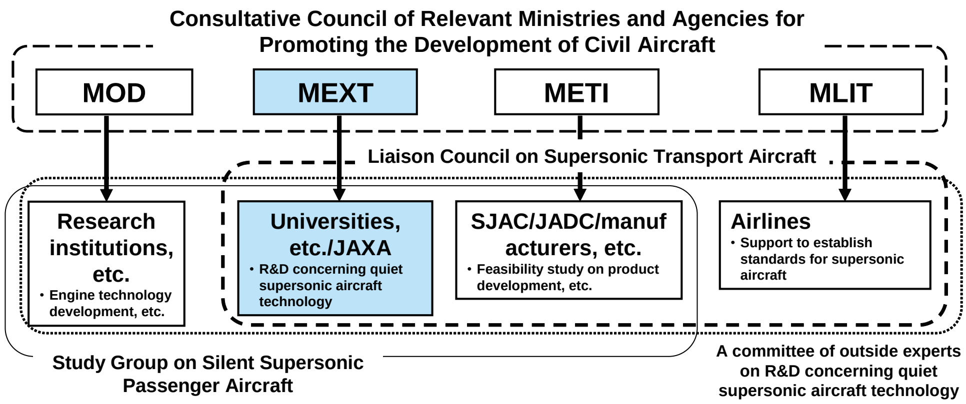
As for small jet aircraft technology being developed under the Research and Development of Environment-Friendly, High-Performance Small Aircraft project, Mitsubishi Heavy Industries Ltd. (MHI) decided on March 28, 2008, to commercialize it as the "Mitsubishi Regional Jet" (MRJ), which will be the first Japanese-developed civil passenger aircraft in approximately 40 years since YS-11. On April 1, 2008, MHI established Mitsubishi Aircraft Corporation, which is responsible for the commercialization of the MRJ.[25]

It should be noted that for the MRJ to be operated as a civil aircraft in Japan, it will need a type certification from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and JAXA will provide technical support to the ministry in this regard.

(2) Quiet Supersonic Experimental Aircraft

Unlike military aircraft, for which only several minutes of supersonic flight is required at a time, Concorde, which was developed jointly by the United Kingdom and France and which was the only supersonic passenger aircraft in the world, was required to fly at supersonic speeds for several hours. Consequently, the necessary weigh reduction, aerodynamic designs and fuel efficiency posed development challenges. Moreover, Concorde was allowed to land at and take off from only a limited number of airports because of its noise level, higher than that of subsonic aircraft, and was prohibited from flying over land at supersonic speeds because of its sonic booms.[26,27]

As shown in Figure 4, JAXA, in cooperation with relevant agencies, is engaging in the quiet supersonic aircraft technology R&D project, which aims to achieve both environmental friendliness, including the reduction of sonic booms, which will be the key to the realization of SST, and fuel efficiency improvement based on weight reduction and aerodynamic drag reduction in addition to reducing noise during the landing and take-off cycle, with a view to participating in a future international SST (supersonic transport) development project on an equal footing.



(1) Liaison Council on Supersonic Transport Aircraft: Established in January 2008 to bring together relevant public and private organizations to discuss ultimate goals, the division of roles and how to collaborate with each other. Comprised of five domestic relevant organizations.

Members: Japan Aircraft Development Corporation (JADC), Engineering Research Association for Supersonic Transport Propulsion System (ESPR), Japanese Aerospace Engines Corporation (JAEC), Society of Japanese Aerospace Companies (SJAC) and Japan Aerospace Exploration Agency (JAXA)

Observers: Ministry of Economy, Trade and Industry (MLIT), Ministry of Education, Culture, Sports, Science and Technology (MEXT), and Ministry of Land, Infrastructure, Transport and Tourism (MLIT), academic experts and airlines

(2) A committee of external experts on R&D concerning quiet supersonic aircraft technology: An external advisory committee to JAXA established in September 2007 to efficiently promote R&D concerning quiet supersonic aircraft technology. Comprised of experts from aircraft manufacturers, airlines and think tanks, among other organizations.

Members: Two members from the academic circles, three from aviation-related organizations, two from airlines, one from a think tank and four from manufacturers

Observers: Ministry of Education, Culture, Sports and Science and Technology (MEXT), Ministry of Economy, Trade and Industry (METI) and Ministry of Defense (MOD:Air Systems Research Center).

(3) Study Group on Silent Supersonic Passenger Aircraft: A study group that was established in October 2005 under the Japan Society for Aeronautical and Space Sciences

Figure 4 : Framework for Implementation of R&D concerning Quiet Supersonic Aircraft Technology

Source: Reference[26]

JAXA has been conducting supersonic aircraft technology R&D activities since 1997. The first stage of JAXA's R&D was intended to acquire design techniques necessary for achieving aerodynamic drag reduction, including the computational fluid dynamics (CFD) inverse design techniquls. Unlike conventional design techniques, which involve iteration between the design evaluations through wind tunnel tests and CFD analysis and the design modifications based on the differences between the evaluation results and the goal, the CFD inverse design techniques determine the shape of the wing based on the assumed goal of achieving the pressure distribution that realizes natural laminar flow. In the first stage of the R&D, JAXA successfully conducted a flight demonstration of a rocket-powered small supersonic experimental airplane launched by a booster rocket, and the successful demonstration flight confirmed the validity of the CFD inverse design techniques.[28]

JAXA has entered into the second phase since 2006 to conduct flight demonstrations using jet-powered and fully autonomous unmanned experimental aircraft to resolve the noise problem by halving the sonic boom level as well as to reduce the aerodynamic drag. As shown in Table 2, JAXA is conducting R&D activities for the experimental aircraft and associated flight test plans, and plans to start the full scale development in fiscal 2010, after a phase-up decision by an mid-term evaluation in fiscal 2009, to conduct flight demonstrations around the mid-2010s.[26] Regarding a study on the supersonic experimental aircraft design, the multidisciplinary design optimization approach has been developed and it is expected to contribute to not only the design of supersonic aircraft but also that of subsonic aircraft.[27] The multidisciplinary design optimization approach produces an aircraft design by going further than the CFD inverse design and dealing with problems involving a number of disciplines, including structural mechanics, aerodynamics and aero acoustics, in an integrated manner.

Also underway is a concept study on a hypersonic aircraft, which would fly at a cruising speed of around Mach 5 and cross the Pacific in about two hours. Since an engine for hypersonic aircraft produces propulsion force through the combustion of fuel and air taken in from the

Table 2 : Broad Schedule of R&D concerning Quiet Supersonic Aircraft Technology

Fiscal year	2006	2007	2008	2009	2010	2011	2012	Around the mid-2010s
I. Major milestones		▽ Preliminary evaluation		▽ mid-term evaluation		Concept of small SST with a halved sonic boom intensity ▲	Concept ofenvironment-friendly small SST	Performance target achievement evaluation of small SST
II. Technological targets								
(1) Halving of the sonic boom intensity: 0.5psf or less					▽ Analysis-based evaluation			▽ Achievement evaluation based on flight tests and analysis
(2) Noise during take-offs and landings: Conforming to ICAO Chapter 4							▽ Achievement evaluation based on element tests and analysis	▽ Achievement evaluation based on ground tests and analysis
(3) Lift-to-drag ratio during cruising: 8.0 or more							▽ Analysis-based evaluation	▽ Achievement evaluation based on ground tests and analysis
(4) Structural weight: 15% reduction compared with an all-metal airframe							▽ Evaluation based on partial structural prototyping	▽ Analysis-based achievement evaluation
III. Development of a flight test system for quiet supersonic experimental aircraft and flight tests								
(1) Development of a flight test system for quiet supersonic experimental aircraft	Concept study	Concept study	Design study	▽ Completion of a preliminary desing; Design study	▽ Completion of a detailed design; Development	Development	Development	▽ Completion of development
(2) Flight tests of quiet supersonic experimental aircraft			Study on flight test plans, etc.	Study on flight test plans, etc.	Drafting of detailed flight test plans, etc.	Drafting of detailed flight test plans, etc.	Drafting of detailed flight test plans, etc.	▽Start of flight tests; Flight tests

Source: Reference[26]

atmosphere, unlike a rocket engine, and thus enables the reduction of on-board propellant mass, the concept of using this engine for the first stage of a space transportation system is also under consideration.[28]

3-2 Europe

(1) European Aeronautics: A Vision for 2020 and the Advisory Council for Aeronautics Research in Europe (ACARE)

A report entitled "European Aeronautics: A Vision for 2020" (hereinafter referred to as the "European Aeronautics Vision 2020") was issued in January 2001.[29] The report proposed, as goals to be achieved through partnership among government, industry and academic sectors, (1)"Responding to society's needs" to advance and strengthen quality and affordability, safety, environment, and air traffic management (ATM) aspects, as well as (2)"Securing global leadership" to maintain and strengthen the European aeronautics industry's world top-level international competitiveness, and (3)"Establishing supportive public policy and regulation" to adopt more flexible approaches to adapt to market changes, to strengthen public R&D activities, to facilitate greater integration of European, national and private research programs, to ensure education policies that nurture human resources for aeronautics, to encourage human resource mobility among EU nations, to promote electronic networks and eCommerce, and to strengthen relationships with the International Civil Aviation Organization (ICAO) and other international institutions that affect European air transportation activities.

The establishment of the Advisory Council for Aeronautics Research in Europe (ACARE) as a European Technology Platform (ETP) was also recommended in order to coordinate the interests of the parties involved in the aeronautics sector.[29,30] ACARE conducted a study on the prioritization of civil air transport R&D subjects that should be realized by 2020 to respond to society's needs as prescribed in the European Aeronautics Vision 2020 and drew up the Strategic Research Agenda (SRA). As shown in Figure 5, a report issued in October 2002 identified the five challenges (quality and affordability, safety, environment, European Air Transport System efficiency and security), with security included among the five challenges following the multiple terrorist attacks using hijacked aircraft that occurred in the United States in September 2001. A report issued in October 2004 identified six high-level target concepts (very low cost, ultra green, customer-orientedness, time efficiency, advanced security and air transport of the future) as the second SRA.[31]

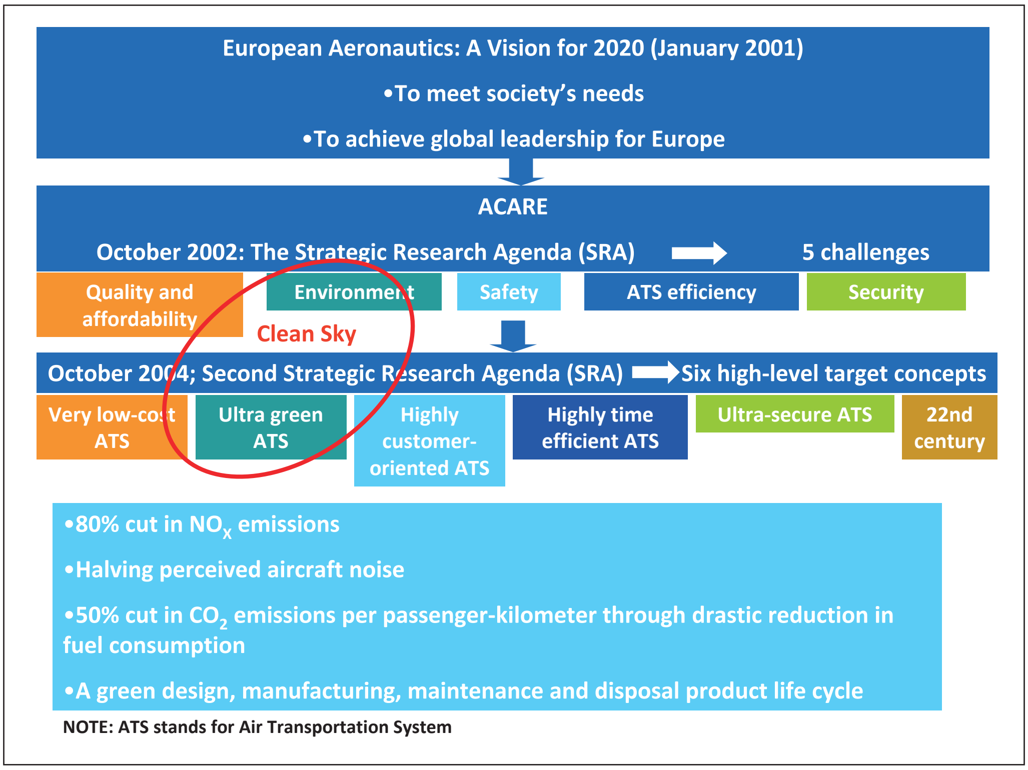


Figure 5 : Strategic Research Agenda for European Aeronautics

Source: Reference[31]

(2) Seventh Framework Programme for EU Research and Development

As shown in Table 3, the seventh framework programme for EU research and development (FP7) has adopted (1) the greening of air transport, (2) increasing time efficiency, (3) ensuring customer satisfaction and safety, (4) improving cost efficiency, (5) protecting aircraft and passengers and (6) pioneering the air transport of the future as challenges to be tackled in the field of aeronautics, based on ACARE's recommendations.[32,33]

R&D activities are classified according to their technology readiness levels. (1) Level 1 covers upstream research and technology development activities from basic research to validation at component or subsystem level through analytical and/or experimental means in the appropriate environment, while (2) Level 2 covers downstream research and technology development activities up to higher technology readiness, centered on the multidisciplinary integration and validation of technologies and operations at a system level in the appropriate environment (large scale flight and/or ground test beds and/or simulators). (3) Level 3 covers research and technology development activities up to the highest technology readiness, in a fully integrated system of systems in the appropriate operational environment.

Among the ongoing Level 3 research and development projects are the Clean Sky Joint Technology Initiative (JTI) and the Single European Sky ATM Research (SESAR), which are implemented outside the framework of ordinary research and development activities under the FP7.

(3) Clean Sky JTI

The Clean Sky initiative conducts advanced technology development and demonstration that will lead to product development in order to significantly reduce the environmental impact of aviation, such as emissions of CO_2, NO_X and noise, through partnerships among the government, industry and academic secters based on the European Aeronautics Vision 2020 and ACARE's recommendations. As shown in Figure 6, with regard to the vehicle development, the Clean Sky initiative conducts element technology development and integrated technology demonstration (ITD) using prototypes for (1) smart fixed-wing aircraft which is equipped with open rotors capable of drastically improving energy efficiency and which realizes ideal natural laminar flow corresponding to flying speed and (2) green regional aircraft, which realizes a significant reduction of emissions of air pollutants and noise near airports and (3) green rotorcraft, which has

Table 3 : Aeronautical R&D activities under FP7

1. Greening of air transport • Areas: Green aircraft, ecological production and maintenance, green air transport operations • To reduce the environmental impact of air transportation by halving CO_2 emissions per passenger-kilometer, reducing NO_x emissions by 80% and halving the perceived noise by 2020 compared with 2001. • To enhance green engine technologies, including alternative fuels technology as well as improved vehicle efficiency of fixed-wing and rotary wing aircraft, new intelligent low-weight structures, and improved aerodynamics. • Issues such as improved aircraft operations at the airport, air traffic management, and green manufacturing, maintenance and recycling processes will be included.
2. Increasing time efficiency • Areas: Aircraft systems and equipment for improved aircraft throughput and time efficient air transport operations • To improve punctuality (to enable 99% of flights to arrive and depart within 15 minutes of their scheduled arrival/departure time) in all weather conditions and significantly reduce the time spent in travel-related procedures (to under 15 minutes for short-haul flights and to under 30 minutes for long-haul flights) at airports while maintaining safety in order to accommodate future growth in air traffic, which could increase three-fold. • To develop and implement an innovative air traffic management (ATM) system within the context of the SESAR initiative, by integrating air, ground and space components, together with traffic flow management and more aircraft autonomy. • Design aspects of aircraft to improve handling of passengers and cargo, novel solutions for efficient airport use and connecting air transport to the overall transport system will also be addressed.
3. Ensuring customer satisfaction and safety • Areas: Passenger-friendly cabin (expansion of the range of in-flight services and improvement in passenger comfort) and passenger-friendly air transport operations, aircraft safety and ATM operational safety • To significantly increase passenger choice and schedule flexibility and to reduce the accident rate to a fifth of the current rate. • To achieve a substantial improvement in the elimination of and recovery from human error and mitigate the consequences of accidents.
4. Improving cost efficiency • Areas: Aircraft development cost, aircraft operational cost and ATM operational cost • To improve the whole business process, from conceptual design to product development, manufacturing and in-service operations, including the integration of the supply chain, and reduce travel charges by reducing the aircraft development, the time to market and aircraft operating costs by 50% and the ATM operational costs by 20% by 2020 compared with 2001.
5. Protection of aircraft and passengers • Areas: Aircraft security and operational security • To prevent hostile action of any kind to incur injury, loss, damage or disruption to travelers or citizens. • To eliminate hazards of hostile on-board or external actions against aircraft and air transportation systems.
6. Pioneering the air transport of the future • Areas: Breakthrough and emerging technologies and step changes in air transport operation • To produce pioneering ideas and create future-oriented technologies, particularly through efforts by universities and research organizations, in order to meet society's needs that may arise in the second half of this century.

Source: Reference[32,33]

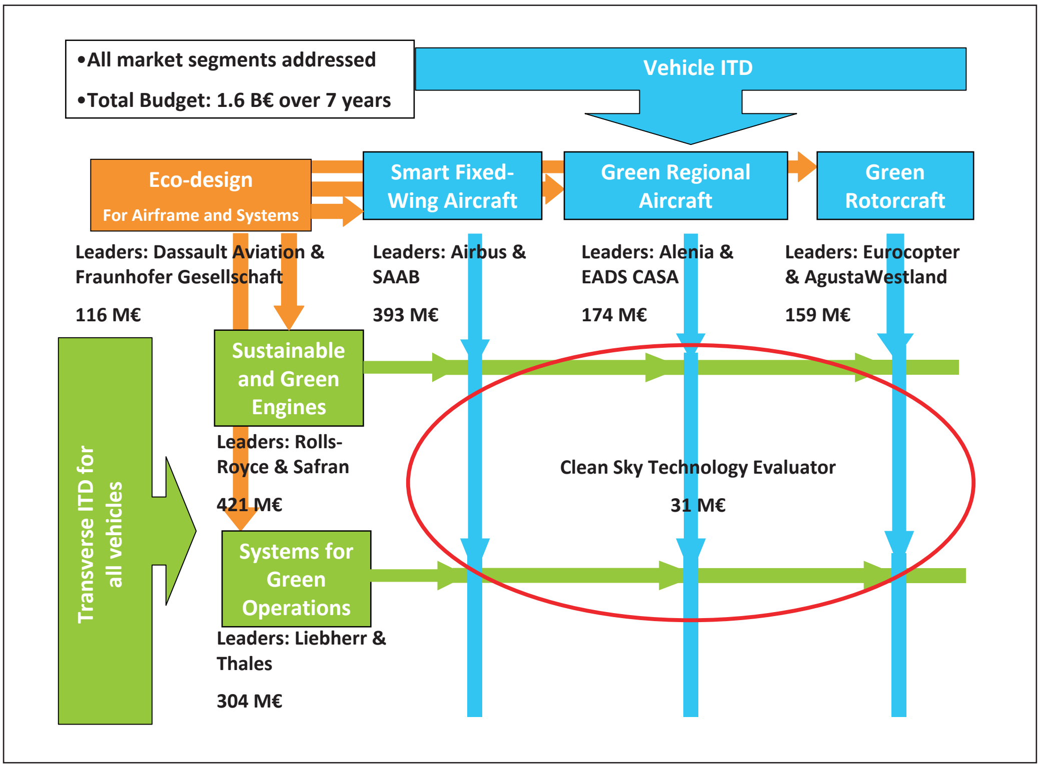


Figure 6 : Integrated Technology Demonstration Projects under the Clean Sky Initiative

Source: Reference[34]

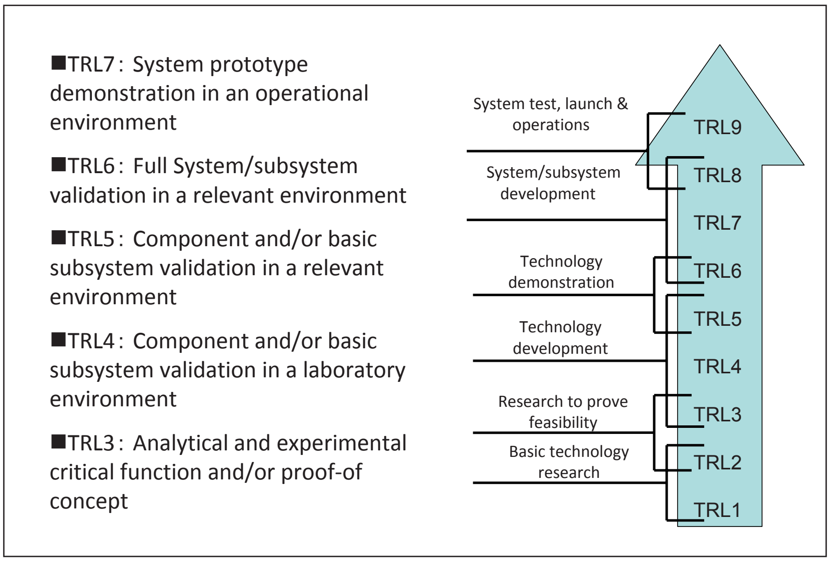


Figure 7 : Technology Readiness Levels (TRLS) and R&D phases

Source: Reference[35]

similar environment-friendly features to those of green regional aircraft. With regard to the transverse ITP for all vehicles, the Clean Sky initiative conducts element technology development and integrated technology demonstration using prototypes for (4) sustainable and green engines indispensable to the development of smart fixed-wing aircraft, green regional aircraft and green rotorcraft and (5) systems for green operations, which reduce energy consumption through the application of electrical auxiliary power units and hydraulic systems and the optimization of flight trajectories to mitigate the environmental impact near airpots as well as during cruising. With regard to the airframe and systems, the initiative develops element technologies and conducts integrated technology demonstration using prototypes for (6) the eco-design that aims to reduce the environmental impact throughout the overall life cycle of aircraft from design to manufacturing to dismantling.[34]

A total of approximately 1.6 billion euros are budgeted for the Clean Sky initiative over the seven-year period between 2008 and 2014, with half of the funds being provided by the European Commission and the other half by the participating companies. Individual IDT projects are led by major European companies. Small and medium-size aeronautics companies in Europe participate in IDT projects through calls for proposals or calls for tenders. As shown in Figure 7, the Clean Sky initiative aims to achieve a technology readiness level of TRL6 or higher to enable product development.[35]

3-3 United States

(1) The U.S. Federal Government's Policy

The National Science and Technology Council (NSTC) was established on November 23, 1993, as a cabinet-level council within the executive branch to coordinate science and technology policy. The NSTC is chaired by the President, and its membership consists of the Vice President, the Director of the Office of Science and Technology Policy (OSTP), Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other executive branch officials.[36] An Executive Order entitled the"National Aeronautics Research and Development Policy," approved by the President in December 2006, was the U.S. federal government's first policy for aeronautics research and development for the period leading to 2020. The Aeronautics Science and Technology Subcommittee (AS&T) of the NSTC's Committee on Technology (COT) drew up the "National Plan for Aeronautics Research and Development and Related Infrastructure" in December 2007 in accordance with the provisions of this policy.[37]

As shown in Table 4, the National Plan set goals, and near-term, mid-term and far-term objectives regarding four fields of aeronautical research and development — (1) mobility, (2) national security and homeland defense, (3) aviation safety, and (4) energy and environment — as well as listed plans for research, development, test and evaluation (RDT&E) infrastructure.

As will be mentioned in Section 4-1 (1), "I. Mobility" of Table 4 set the goal of dealing with an expected significant increase in traffic volume by substantially improving the functions and performance of the air traffic management system through the introduction of the Next Generation Air Transportation System (NextGen). "IV. Energy and Environment" set the goal of developing alternative fuels derived from domestic sources and reducing the environmental impact of aviation through a significant improvement in energy efficiency.

The National Aeronautics Research and Development Policy also prescribes the division of roles between federal government agencies. The policy stipulates that whereas the Department of Defense (DOD), the Federal Aviation Administration (FAA), the National Science Foundation, the Department of Homeland Security (DHS) and the Department of Commerce (DOC) should conduct R&D within their own jurisdictions, the National Aeronautics and Space Administration (NASA) should maintain broad fundamental research efforts, including those essential for human and robotic missions, to preserve the intellectual stewardship and mastery of aeronautics core competencies to retain the nation's world-class aeronautics expertise.[36]

(2) NASA's Aeronautics Research and Development Activities

Under its long-term plan, NASA seeks to implement programs while maintaining the right balance between science, manned space exploration and aeronautics, and intends for aeronautics to develop knowledge in basic research fields as well as to conduct technology development to improve aircraft safety and deal with an increase in air traffic.[38] Goals that should be achieved in the field of aeronautics include (1) developing by 2016 tools, techniques and technologies to improve both conventional and new aircraft safety under the Next Generation Air Transportation System (NextGen), which is scheduled to start operation around 2025 for the air traffic management (ATM), (2) developing by 2016 advanced technologies that satisfy the requirements for the traffic volume and mobility of the NextGen while maintaining safety, (3) developing by 2016 the multi-disciplinary analysis and optimization (MDAO) approach, which will enable quantitative evaluation of the performance of various configurations of aircraft at all speeds from subsonic to supersonic and to hypersonic speeds, and (4) ensure continued provision of NASA's strategically important wind tunnel test facilities and ground test facilities.

Table 4 : Goals of U.S. National Plans concerning Aircraft Development and Related Facilities

I. Mobility Goal 1: Develop reduced aircraft separation in trajectory- and performance-based operations Goal 2: Develop increased National Airspace System capacity by managing NAS resources and air traffic flow contingencies Goal 3: Reduce the adverse impacts of weather on air traffic management decisions Goal 4: Maximize arrivals and departures at airports and in metroplex areas Goal 5: Develop expanded aircraft capabilities to take advantage of increased air transportation system performance
II. National Security and Homeland Defense Goal 1: Demonstrate increased cruise lift - to - drag and innovative airframe structural concepts for highly efficient high-altitude flight and for mobility aircraft Goal 2: Develop improved lift, range, and mission capability for rotorcraft Goal 3: Demonstrate reduced gas turbine specific fuel consumption Goal 4: Demonstrate increased power generation and thermal management capacity for aircraft Goal 5: Demonstrate sustained, controlled, hypersonic flight
III. Aviation Safety Goal 1: Develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems Goal 2: Develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air Goal 3: Demonstrate enhanced passenger and crew survivability in the event of an accident
IV. Energy and Environment Goal 1: Enable new aviation fuels derived from diverse and domestic resources to improve fuel supply security and price stability Goal 2: Advance development of technologies and operations to enable significant increases in the energy efficiency of the aviation system Goal 3: Advance development of technologies and operational procedures to decrease the significant environmental impacts of the aviation system

Source: Reference[37]

NASA's Aeronautics Research Mission Directorate (ARMD) aims to achieve the goals under the long-term plan with four pillars of fundamental aeronautics, aviation safety, air traffic and aeronautics test facilities.[39] ARMD's activities cover (1) with regard to the air traffic, research necessary for the NextGen , (2) with regard to the aviation safety, research concerning preventive safety for both conventional and new aircraft under the existing ATM and the NextGen, (3) with regard to the aeronautics test facilities, maintenance and improvement of the test facilities and equipment necessary for the United States, including the development of new test equipment and techniques, and (4) with regard to the fundamental aeronautics, advanced research aimed at discovering the principles of flight applicable to any atmosphere, on the Earth or other planets of the Solar System, and at any speed .

Regarding the fundamental aeronautics, R&D projects concerning subsonic fixed wing aircraft, subsonic rotary wing aircraft, supersonic aircraft and hypersonic aircraft are underway.[40] The subsonic fixed-wing aircraft and the supersonic aircraft are classified into the first generation (N+1), the second generation (N+2) and the third generation (N+3), which could enter into service around 2015, around 2020 and around 2030-35, respectively, with R&D goals set for each generation. Another notable thing is that in the hypersonic aircraft research, concept studies are underway concerning a Two-Stage To Orbit (TSTO) space transportation system, which uses an air-breathing hypersonic engine for its first stage and concerning the entry, descent, and landing (EDL) of a large structure weighing approximately 30 tons, which may be used for future human space exploration. In these research activities, tools for the multi-disciplinary analysis and optimization (MDAO) that enables efficient design trade-offs are also under development. ARMD is cooperating with Pratt & Whitney in ground tests of the geared turbofan engine, which is fuel efficient and is planned to be installed onboard the MRJ, and with Boeing Co. in flight tests for X-48B, an experimental blended wing body (BWB) airplane. In addition, ARMD has been implementing the NASA Research Announcement (NRA) program since fiscal 2006 in order to maintain and strengthen U.S. aeronautics industry's capabilities in the field of basic research. In fiscal 2008, research contracts were awarded under the NRA program to six industry teams to study advanced concepts for subsonic and supersonic aircraft that could enter into service around 2030 to 2035. Environmental friendliness is included among the major subjects of the study, and the total value of the contracts, whose term was approximately 18 months, was $12.4 million.[41]

4 Comparative Analysis of Research and Development Activities

4-1 Moves toward Environmental Friendliness

As shown in Table 5,[42] short- and medium-term technological measures to mitigate air transportation's environmental impact include retrofits[43] of winglets that reduce atomosrpheric drag caused by wingtip vortexes, the development of plant-derived and other alternative fuels[44] to oil-derived kerosene, and, in the long term, the introduction of new environment-friendly aircraft will become essential. Regarding operations, it will be important in the short- to medium-term to introduce a next-generation air traffic management (ATM) system, in addition to replacing the conventional landing method, which involves the repeated alternations of gliding and powered flights, with the continuous descent approach (CDA).

As we mentioned in Chapter 2, achieving environmental friendliness is becoming an increasingly urgent issue for air transportation amid the concern about an increase in the environmental impact of aviation expressed by the IPCC and the expected enforcement that emissions from flights taking off and landing at airports within the EU region will in principle be subject to the EU Emission Trading Scheme (EU-ETS) starting in 2012. Against this background, as we described in Chapter 3, Japan, the United States and Europe are implementing R&D programs to make air transportation environment-friendly through government-industry-academia collaboration. Below, we will explain the Japanese, U.S. and European R&D activities that demand particular attention.

Table 5 : Environmental mitigation strategies concerning air transportation

	Mitigation strategy	Environmental impact			Relative economic cost or benefit	Timeframe	Impact
		Noise	Air quality	Global climate			
Technology	Source shielding	+	N/A	×	− $ (Cost)	Short	Existing aircraft
	Retrofits (e.g. winglets)	N/A	N/A	++	− $ (Setup cost) + $$ (Fuel benefit)	Short	Existing aircraft
	Alternative fuels	N/A	+	++	− $$ (Cost)	Medium	Existing aircraft?
	All-new designs	++	++	++	− $$$ (Setup cost) + $$ (Fuel benefit)	Long	New fleet
Operations	CDA	+	+	N/A	− $ (Fuel benefit)	Short	Airport
	De-rated thrust	+	+/−	N/A	+ $ (Benefit)	Short	Aircraft
	Steep approach	+	+	N/A	− $ (Cost)	Medium	Airport
	ATM efficiency	+	+	+	− $$ (Setup cost) + $ (Fuel benefit)	Medium	System

Source: Reference[42]

(1) Next-Generation Air Traffic Management (ATM) System

According to some estimates,[45] air traffic volume will almost double by around 2025 compared with around 2000. It will be difficult to deal with such an increase through a conventional air traffic system based on voice communications between aircraft and ground controllers using ground-based radar systems. In order to resolve air traffic congestion problems such as delayed arrivals and take-offs at airports and slow flights, it will be essential to introduce an air traffic system that enables exchanges of information and data, such as weather forecasts and the location and speed of neighboring aircraft, between pilots and ground controllers like the Internet, using navigation satellites such as GPS. The United States is developing the Next Generation Air Transportation System (NextGen), and is aiming to start operating the system around 2025.[46]

The European Union is implementing the Single European Sky ATM Research Programme (SESAR) under the Single European Sky (SES) policy, which will organize airspace uniformly, rather than dividing it into compartmentalized air traffic control areas, with a view to realizing the new air traffic control system around 2020.[47] In Japan, the Ministry of Land, Infrastructure, Transport and Tourism is engaged in a similar project using the MT-SAT multi-purpose satellite as well as an R&D project to develop DREAMS (the Distributed and Revolutionary Efficient Air-traffic Management System) is being conducted, which will enable autonomous navigation for small aircraft, in light of the unique circumstances of Japan.[48]

The introduction of such next-generation ATM systems is expected to reduce CO_2 emissions per passenger-kilometer by approximately 10%.[47] In order to further reduce CO_2 emissions as well as aircraft noise around airports and air pollutions caused by nitrogen oxides and unburned hydrocarbons, it will be essential to introduce environment-friendly aircraft with significantly lower gas emissions and noise compared with conventional aircraft.

(2) Technology Essential for Environment-Friendly Aircraft

The flying range per unit of energy consumed is obtained through the formula below. Va/c represents the aircraft speed, (L/D) the lift-to-drag ratio, TSFC the energy consumption rate per rated thrust, and W the aircraft weight, which is the total of the dry weight (W_0), the payload weight (W_{PL}) and the fuel weight (W_{Fuel}).

$$-dR/dW = Va/c \times (L/D)/TSFC/W$$

As indicated by the above formula, a) reduction of the aircraft weight, b) an improvement in the engine efficiency, c) an improvement in the lift-to-drag ratio (L/D) and d) an increase in the energy intensity per unit of fuel mass will be the key to reducing emissions of greenhouse gases such as CO_2 by increasing the flying range per unit energy consumed.[49]

a) Reduction of the Aircraft Weight

As shown by the case of B787,[50] the use of carbon fiber reinforced plastic (CFRP), which is light and strong, is effective in reducing the aircraft weight. However, as CFRP is usually comprised of layers of a semi-cured sheet-like composite material called pre-preg, its manufacturing involves many processes and requires an expensive manufacturing chamber called an autoclave, which uses high temperature and pressure, resulting in high manufacturing costs.[51,52] The Japan Aerospace Exploration Agency (JAXA) is conducting research concerning the application of the vacuum assisted resin transfer molding method (VaRTM) to the manufacturing of aircraft structure materials. The VaRTM method, which does not require either pre-pregs or an autoclave, injects into the mold fibers that are layered and formed into the prescribed shape through vacuuming, leading to a significant cost reduction. Through many years of research, including the prototyping of a 6 m long wing structure , know-how about testing techniques and safety evaluation standards has been acquired. As a result, it has been decided that the MRJ will use CFRP manufactured through the VaRTM method as the material for its tail in addition to using CFRP manufactured through the conventional manufacturing method as the material for the wings. The use of CFRP manufactured through the VaRTM method in an experimental quiet supersonic aircraft mentioned in Section 3-1-(2) is also under consideration.

b) Improvement in the Engine Efficiency

The thrust (F) generated by a jet engine is as shown in the formula below. Δm represents the mass of the fluid emitted by the jet engine per unit time, V_{jet} the speed of the jet stream and $V_{a/c}$ the aircraft speed. The fuel consumption is proportional to the square of V_{jet} (fuel consumption $\propto V_{jet}^2$)

$$F = \Delta m \times (V_{jet} - V_{a/c})$$

The mass of CO_2 emitted by a jet engine is proportional to the fuel mass consumed. As the fuel consumption mass is proportional to the square of V_{jet} while the thrust (F) is proportional to Δm and (V_{jet}-$V_{a/c}$), increasing the thrust, F by increasing in Δm is more fuel-efficient and contributes more to the reduction of CO_2 emissions than doing so by increasing V_{jet}, which leads to increasing the fuel consumption. Therefore, the turbofan engine, which increases the mass of air that flows outside the combustion chamber relative to the mass of air that flows into it, has become popular.[53] Although the bypass ratio, which represents the ratio of the volume of air that flows outside the combustion chamber to the volume of air that flows into it has been expanded, the advantage of a higher bypass ratio is becoming smaller because of an increase in aerodynamic drag caused by an expansion of the cross-section area of the engine and an increase in the weight caused by an expansion of the nacelle size. Consequently, a new approach is being explored. The geared turbofan engine, being developed by Pratt & Whitney of the United States is designed to ensure that both the low-wind-speed turbine and the fan rotate at the optimum speed by placing a reduction gear between the two. Also under R&D is an open rotor, whose turbine rotor blade is not covered by a nacelle so as to increase the bypass ratio. With regard to the open rotor, there are a variety of problems that must be resolved, including safety problems such as the risk of a broken rotor damaging the fuselage due to the absence of a protective cover, difficulty in assembly and maintenance and the louder big noise produced by the uncovered rotor. Under the Clean Sky initiative, efforts are underway to resolve these problems.

c) Improvement in the Lift-to-Drag Ratio

In order to improve the lift-to-drag ratio, it is necessary to limit the generation of vortex and realize natural laminar flow around the aircraft. Therefore, in the integrated technology demonstration of the Smart Fixed-Wing Aircraft under the Clean Sky initiative, R&D is underway in order to realize appropriate natural laminar flow around the wing according to the aircraft speed. As it is impossible to achieve a significant improvement in the lift-to-drag ratio based on the conventional fuselage-wing configuration (the combination of a cylinder-shaped fuselage and wings), some people think that an innovative airframe configuration needs to be adopted. Therefore, configurations such as the flying wing (FW) and the blended wing body (BWB) are under consideration. Since fiscal 2007, NASA has been conducting flight tests of a scale mode of the X-48B experimental aircraft, shown in Figure 8, in cooperation with the U.S. Air Force and Boeing Co.[54] These configurations are expected to not only lead to an increase in the passenger capacity but also reduce noise by enabling the installation of engines above the airframe.[55]

Figure 8 : X-48B Undergoing a Flight Test

Source: NASA

d) Alternative Fuels

Currently, kerosene is superior to any other fuel in terms of the energy intensity per unit mass fuel. Although hydrogen has the potential to replace kerosene as the main aviation fuel, there is a cost problem, because not only aircraft must be modified to adapt to the hydrogen fuel but also ground facilities must be reconstructed accordingly.[55] As indicated by the case of the United States described in Section 3-3-(1), the introduction of alternative fuels is deemed to be essential in order to secure a stable supply of fuels. Therefore, drop-in fuels that are compatible with existing aircraft and ground facilities are under development.[56] In addition to the gas-to-liquid (GTL) technology, the biomass-to-liquid (BTL) technology is promising in terms of reducing CO_2 emissions.[57] However since, the use of edible plant as fuel materials is controversial, a composite fuel of an algae-based biofuel and kerosene is under development.[44,58]

4-2 Comparison of Japanese, U.S. and European Research Targets

(1) Subsonic Passenger Aircraft

Table 6 shows a comparison of the targets for the reduction of environmental impact in the Japanese, U.S. and European R&D projects for the development of subsonic aircraft. It should be noted that the Japanese targets are those for the engines alone. While it is simple to compare the Japanese projects and the U.S. and European projects with regard to NO_X emissions, which derive exclusively from engines, a simple comparison regarding noise is impossible, because landing gears are the main source of noise during landings and take-offs, for example. It should be noted that the Advisory Council for Aeronautics Research in Europe (ACARE) sets the airframe contribution to the targeted reduction of CO_2 emissions at approximately 20 to 25%, the engine contribution at 15 to 20% and the ATM contribution at 5 to 10%.[59] Improving fuel efficiency through high-temperature, high pressure combustion processes involves a trade-off in terms of emissions, as the processes reduce CO_2 emissions but increase NOx emissions.[55] The Japan Aerospace Exploration Agency (JAXA) is developing a “clean engine” using the lean premixed combustion system, which mixes fuel with a sufficient amount of air for perfect combustion in advance in order to significantly reduce NOx emissions.[60] As shown in Table 14, this project is expected to achieve a performance comparable to the U.S. and European projects. We hope that further R&D efforts will lead to a market launch of a Japanese-developed environment-friendly engine that is internationally competitive.

(2) Supersonic Passenger Aircraft

Table 7 shows a comparison of the targets of the Japanese and U.S. projects for the development of supersonic passenger aircraft. As we mentioned in Section 3-1-(2), significant reduction in sonic booms generated by supersonic flights will be the key to the development of supersonic passenger aircraft.

Table 6 : Comparison of Japanese, U.S. and European Targets for Environmental Impact Mitigation concerning Subsonic Passenger Aircraft

Country/region	Japan		Europe	U.S.		
Name	Eco-engine	Clean engine	ACARE	N+1	N+2	N+3
Target Year	2010	2012	2020	2015	2020	2030-35
Noise Margin NOTE 1	-20 dB	-23 dB	-30 dB	-32 dB	-42 dB	NOTE 4
LTO NO_X Emissions NOTE 2	-50%	-80%	-80%	-65%	-78%	-78% or more
CO_2 Emissions	-10%	-15%	-50% NOTE 3	-33%	-40%	-70% or more

NOTE 1: Margin relative to ICAO Chapter 4
NOTE 2: Margin relative to the ICAO CAEP4 standard
NOTE 3: Including the expected reduction amount through SESAR
NOTE 4: 55LDN (day-night average sound level)

Source: Reference[21,30,32,40]

Table 7 : Comparison of Japanese, U.S. and European Targets concerning Supersonic Passenger Aircraft Development

Country	U.K./France	Japan	U.S.		
Name	Concorde	Quiet supersonic experimental aircraft	N+1	N+2	N+3
Target Year	1976	Around the mid-2010s	2015	2020	2030~35
Cruising Speed	M2.05	> M1.4	M1.6~1.8	M1.6~1.8	M1.6~1.8 NOTE 5
Flying Range (NM) NOTE 1	3,550	N/A	4,000	4,000	6,000
Passenger Capacity	100	N/A (Unmanned)	6-20	35-70	100-200
Sonic Boom	2~3 psf NOTE 6	< 0.5 psf	NOTE 7	NOTE 7	NOTE 8
Noise Margin NOTE 2	N/A	-αdB	0dB	0~-10dB	-10~-20dB
NO_X EI NOTE 3	Approx.20	N/A	(comparable to subsonic aircraft)	< 10	< 5
Fuel Efficiency NOTE 4	Approx. 2	N/A	1.0	3.0	3.5~4.5

NOTE 1: 1 NM = 1.85km
NOTE 2: Margin relative to ICAO Chapter 4
NOTE 3: NO_X emission index: Volume of nitrogen oxide emissions per unit fuel consumption during cruise. Expressed in the unit of "gNO_X/kg fuel."
NOTE 4: Passenger number times mile/lb fuel
NOTE 5: Value during a low-boom flight. The value is M2.0 when there is no restriction on flight conditions.
NOTE 6: A unit expressing pressure intensity in terms of "$lb/ft.^2$" 1 psf=47.88Pa
NOTE 7: 65-79PLdB (specified in terms of the level of noise perceptible to the human ear, rather than the level of "perceived loudness," which represents physical pressure; affected by the rise time and sound spectrum of the sonic boom)
NOTE 8: The value is 65-70PLdB during a low-boom flight and 75-80PLdB when there is no restriction on flight conditions.

Source: Reference[21,30,32,40]

JAXA plans to conduct a flight test of such aircraft around the mid 2010s, with a view to significantly reducing sonic booms compared with Concorde. The plan has drawn the attention of NASA, leading to joint research activities concerning the sonic boom reduction by JAXA and NASA.[61] We hope that Japan will develop its own supersonic aircraft technology, thus acquiring the ability to participate in a future international development project on an equal footing. It should be noted that ICAO is considering environmental standards for supersonic passenger aircraft.[62]

4-3 Basic Research / Technology Development and Product Development

Under the Seventh Framework Programme (FP7) of the European Union (EU), R&D activities are broadly classified by targeted technical readiness levels into the "basic technology research and feasibility studs" (TRL1-3), "the technology development" (TRL3-5) and "the technology demonstration" (TRL5-6). Under the Clean Sky Joint Technology Initiative in particular, technology development and demonstration activities are underway through government-industry-academia collaboration outside the framework of ordinary FP7-related R&D projects, with a view to achieving TRL6 or higher, which will enable product developments. The European aeronautics industry will thus pursue the product development based on the achievements of the technology development and demonstration under the Clean Sky initiative.

The U.S. Government Accountability Office (GAO) has issued recommendations aimed at

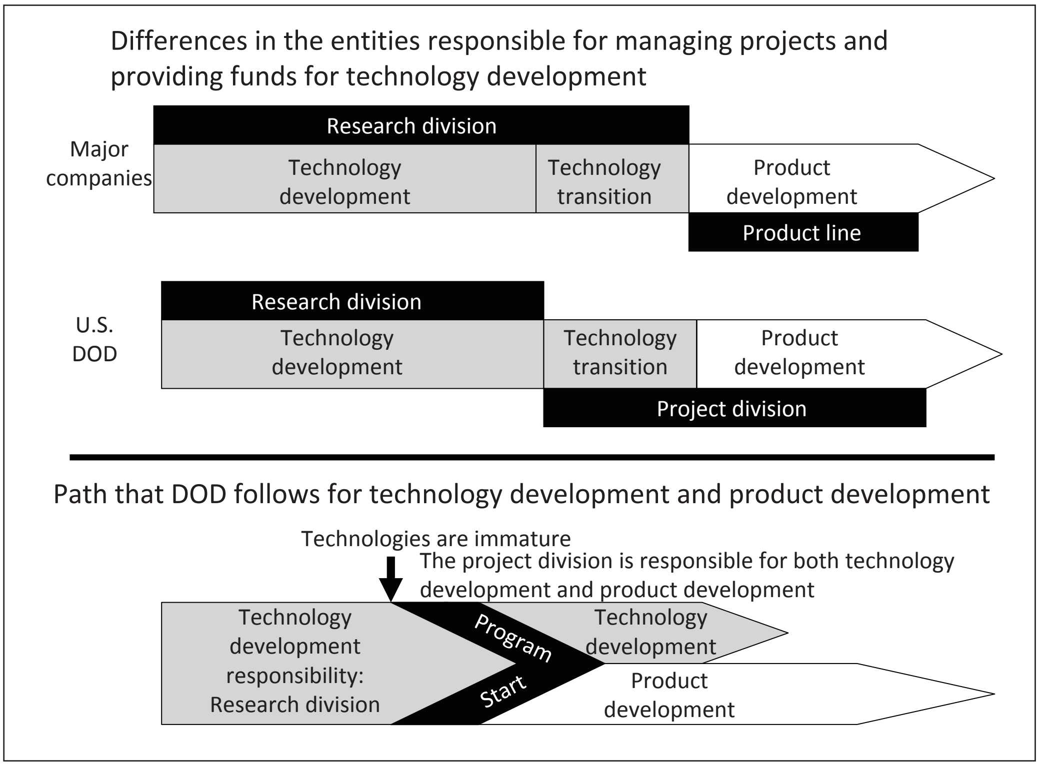


Figure 8 : GAO's Comparison of Technology and Product Development Approaches

Source: Reference[65]

resolving problems that have often occurred at the Department of Defense (DOD), such as development cost overruns, schedule delays and performance shortfalls, by comparing private-sector companies' R&D practices based on the technology readiness level (TRL) approach and the R&D practices adopted by DOD and NASA. Recently, GAO pointed out that problems such as cost overruns, schedule delays and performance shortfalls often occur in the process of technology transition, which is the point of transition from technology development to product development, because, as shown in Figure 8, technologies, including those not ready for transition, are moved too early from the research division to the project division in the absence of specific requirements for transition set by the project division.[65] It argued that as in the case of development by private-sector companies, the research division, rather than the project division, should continue the technology development until technologies become ready for application to the product development, with specific requirements set for transition.

Under the current circumstances of Japan's aeronautics industry, it is of course necessary that relevant organizations work together in all stages of R&D concerning the environment-friendly small aircraft through government-industry-academia collaboration. However, it is desirable that in the future, Japan's aeronautical technology development capability will be strengthened according to a roadmap and specific interface requirements agreed upon by the interested parties by utilizing the whole R&D cycle involving basic research by universities and research organizations, technology development and demonstration by R&D agencies such as the Japan Aerospace Exploration Agency (JAXA) and product development and data feedback by the aeronautics industry based on aircraft production and operations.

5 Conclusion

While Japan leads the world in environmental technology, it is lagging in civil aircraft development, as is shown by the fact that development has just started for a Japanese small passenger jet aircraft that will be the first passenger plane to be developed in Japan in 40 years since YS-11. Japan should make increased contributions to the fight against global warming in the field of air transportation by enhancing its aeronautical technology development capability. In the United States and Europe, medium- and long-term aeronautical projects, including the development of supersonic passenger aircraft, are underway, with targets set for the year 2020 and beyond. We believe that it is important for Japan, too, to implement medium- and long-term projects. The benefits of an advance in aeronautics science and technology are not limited to activities within Earth's atmosphere. NASA is studying the concept of (1) the Two Stage To Orbit (TSTO) space transportation system, which uses an air-breathing hypersonic aircraft instead of a rocket as the first stage and a rocket-propelled shuttle as the second stage, and (2) the entry, descent, and landing (EDL) of a large structure weighing approximately 30 tons in Mars' thin atmosphere as a future concept study for supersonic and hypersonic R&D. The development of aeronautics S&T will expand the frontier of our activities beyond the Earth's atmosphere to its orbital space and to other planets like Mars.

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