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Cooperative transparency

Modernization of Open Skies aircraft and sensors in tense times[1]

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Abstract

Imagine you fly over the territory of a potentially unfriendly neighboring state, you take photographs of it, and no one shoots you down. In fact, the state actually provides you with the infrastructure to carry out your flight. This is regular practice during Open Skies flights. The 34 state parties of the Treaty on Open Skies have opened their full territory from 'Vancouver to Vladivostok' to cooperative observation flights. The Treaty supports mutual transparency of major military assets which are visible in the open. Both the observing and the observed party get copies of the images taken, a basis of avoiding misperceptions. The images have a high degree of undisputed authenticity. The Open Skies Treaty continues to function fairly well in spite of tense East West relations.
Originally film cameras at 30 cm resolution were used. The transition to digital cameras has triggered an ongoing modernization process. Russia and Germany have acquired new dedicated Open Skies aircraft. The United States has established a budget for the acquisition of two new long-range aircraft. This paper will focus on treaty implementation, new aircraft and different configurations of digital aerial cameras acquired by the Russian Federation, the US, Germany and Romania.

1. Introduction

The Treaty on Open Skies has been, from its beginning, a multi-facetted, although little noticed, microcosm and mirror of changing East-West security relations and

[1] Download from http://www.peasec.de/paper/2019/2019_SciencePeaceSecurity_Proceedings-TUprints.pdf, pp. 139

[2] The author has followed the development of Open Skies from the very beginning. He initiated and led a research project on contributions of multispectral imaging in support of arms control monitoring. Based on this work he was invited to support the German Foreign Ministry in preparing the first Open Skies Review Conference in 2005. Subsequently he has participated as an observer in the work of the Informal Group on Sensors (IWGS) of the Open Skies Consultative Commission (OSCC).

regional status conflicts in Europe. In particular, after entry into force in January 2002 the tensions between the Russian Federation on the one hand and Western states on the other were accentuated by a step-by-step deterioration of the East-West arms control architecture: Withdrawal of the United States of America (US) from the Anti-Ballistic Missile Treaty in 2002, failure of NATO states to ratify the Adapted Treaty on Conventional Forces in Europe of 1999 (ACFE), suspension of implementation of the Treaty on Conventional Forces in Europe (CFE) by the Russian Federation in December 2007, the failure of attempts to modernize the Vienna Documents on confidence and security building measures after 2011, and the withdrawal of the US from the INF Treaty and the Russian confirmation of the end of the treaty in 2019. In parallel, various military and political interventions have fuelled mistrust and alienation between the Russian Federation and Western States: The interventions led by the US and France, respectively, in Iraq (2003) and Libya (2011), the recognition of Kosovo by several western states in 2008 and the annexation of Crimea by the Russian Federation in March 2014 as well as the subsequent war in Eastern Ukraine between Ukrainian and separatist forces, the latter ones supported by the Russian Federation. The eastward expansion of NATO since 1999 and the ongoing cooperation of NATO with Georgia and Ukraine have raised concerns in Moscow.
In parallel an ongoing dispute between Greece and Turkey about an accession application by Cyprus to the treaty paralyzed the Open Skies Consultative Commission – the body which takes decisions on treaty implementation – from January 2011 to July 2012 (Spitzer, 2011). Most recently, a veto from Georgia to accept Russian overflights prevented the flight activity of all states in 2018 (Spitzer, 2018). Nevertheless, flights have resumed as normal this year.

Surprisingly, Open Skies implementation survived such challenges and setbacks so far for several reasons:

(i) The major players, the Russian Federation and the US, as well as other parties continue to see the treaty as being in their national security interest. They value the degree of transparency it creates.
(ii) The built-in structure of cooperative implementation and reciprocity in data access makes it attractive to all parties.
(iii) The treaty architecture contains several elements of flexibility: Parties can choose flight paths according to changing security concerns. The treaty provides a procedural framework for certified modernisation of aircraft and sensors.

This paper will report on recent steps in modernizing aircraft and imaging sensors. It will evaluate the contribution of Open Skies cooperative aerial observation to arms control verification and transparency. To begin with, the treaty substance, impediments to full treaty implementation and compliance conflicts are discussed.

Open Skies works mostly in the quiet. It is rarely noticed by the media with the recent exception of some Russian news services and US defence and security journals, and very occasional features in mainstream newspapers. As far as known to the author only few scientific papers have been published on Open Skies sensors after entry in to force, see e.g. (Dunay et al., 2004), (Petrie, 2007), (Spitzer, 2009), (Orych, 2015). A comprehensive overview of publications on Open Skies from 1989 to 2004 can be found in (Dunay et al., 2004).

2. Development and substance of the treaty

2.1 The first three years until signature

The first three years from the initial proposal of the treaty in May 1989 to its signature in March 1992 saw dramatic changes in the political orientation of states in Europe, which had belonged to the Soviet-led Warsaw Treaty Organization. Likewise, there were major shifts in the Euro-Atlantic security relations.

US President H. Bush had initially proposed an Open Skies agreement to the Soviet leadership in order to test General Secretary Gorbachev on his policy claim of Glasnost (openness) and in order to regain initiative in the arms control arena. In contrast to the bilateral Open Skies proposal of President Eisenhower of 1955 the anticipated agreement was intended to include allied states of both sides[3]. The proposal was quickly picked up by member states of NATO, but also by Hungary[4]. A NATO communiqué of December 1989 contained essential elements of the architecture of the treaty that would emerge from its negotiations (NATO, 1989):

- Full territorial access for cooperative observation flights with fixed wing unarmed aircraft,
- Annual flight quota which are to be derived from the size of participating countries,
- Establishment of a multi-lateral treaty among the parties.

It took two major conferences in Ottawa (February 1990) and Budapest (May 1990) as well as an intense negotiation period from September 1991 to March 1992 in Vienna until parties could agree on the treaty. Key elements are:

- Limits of the ground resolution of certified imaging sensors (30 cm for film cameras and video sensors, 50 cm for thermal infrared cameras and 300 cm for synthetic aperture radar),
- Availability of image copies to both the observing and the observed states[5],
- Entitlement of active quota for flights in other countries, combined with the obligation to accept the same number of flights over one´s own territory (passive quota).

[3] For details of Eisenhower´s proposal see e.g.. (Dunay et al., 2004, pp.17-20) and references quoted therein.
[4] Hungary and Canada performed a first Open Skies demonstration flight as early as in January 1990.
[5] Other parties can acquire copies at nominal cost.

- Treaty issues are discussed and decided in the Open Skies Consultative Commission (OSCC) which meets monthly in Vienna and in Review Conferences every five years.

The Russian Federation with Belarus and the US have annual active and passive quota of 42 flights, each[6]. Canada, France, Germany, Italy, the United Kingdom, Ukraine and Turkey have quota of 12 flights each, other countries have less[7]. A detailed account of the negotiation phase and its outcome can be found in (Dunay et al., 2004), (Hartmann, Heydrich, 2000) and (Jones, 2014).

The Treaty was signed by 26 states in March 1992. In the meantime, the German Democratic Republic had acceded the Federal Republic of Germany and the Soviet Union had been dissolved. Four successor states of the Soviet Union joined the treaty: Belarus, Georgia, the Russian Federation and Ukraine[8].

In the arms control arena the successful conclusion and implementation of the CFE Treaty of November 1990 eliminated the force dispositions for massive conventional surprise attacks in Europe. The treaty was originally meant to include an aerial verification system. This was dropped because of lack of negotiation time. In a way the role of aerial monitoring was taken over by Open Skies.

However, Open Skies has a much wider territorial scope. Whereas on-site inspections under CFE are restricted to Europe from the Atlantic to the Urals, Open Skies flights can also cover the vast territories of North America (US and Canada) as well as the Russian Federation east of the Urals[9]. Thus the treaty has a transcontinental dimension and a role in the US-Russian nuclear relationship. Both the US and Russia can use flights to monitor nuclear weapon and missile defence sites in complementation of their satellite reconnaissance assets.

2.2 Trial implementation and entry into force

Entry into force was much delayed by lack of consensus on the treaty in the Russian Federation. The obstacles came from several quarters. Strong opposition to ratification existed in the Russian military which feared espionage. More importantly there was an institutional dead lock between the Russian parliament and President Boris Yeltsin. The treaty was eventually ratified in April 2001, well after Yeltsin had resigned. The treaty was now seen as advantageous to Russia in obtaining information with minimal expenditures (see Dunay et al., 2004, p. 62).

The ten year phase before entry into force was well used. Parties were eager to train their personnel and to test inspection procedures. Over 400 bilateral trial flights were performed upon mutual agreement. Some of the test flights yielded relevant information about Russian military equipment which had been relocated east of the

[6] The Russian Federation and Belarus have formed a group of parties with joint quota.

[7] See (Dunay et al. 2004, p. 45) for a table of flight quota.

[8] Kyrgyzstan signed the treaty in 1998 but never ratified it.

[9] On-site inspections under the Vienna Document on Confidence and Security Building Measures cover Europe from the Atlantic to the Urals including the three Caucasus states (Armenia, Azerbaijan and Georgia) plus the territories of the five Central Asian Republics. The latter ones are not parties of the Open Skies Treaty.

Urals. Germany hosted two trial certifications of five foreign aircraft each in 2000 and 2001. This created the basis of practical experience for the successful certification of aircraft and sensors of ten countries after entry into force of the treaty (1 January 2002)[10]. In addition C130 aircraft with a joint sensor pod of a group of ten further countries (the so called Pod Group) were successfully certified. For an account of the trial implementation phase and the mission practice after entry into force, see (Dunay et al., 2004).

2.3 Accession of other parties and flight activity

Eight countries acceded the treaty after entry into force. These included the three Baltic States, Bosnia-Hercegovina, Croatia, Finland, Slovenia and Sweden. Today the treaty comprises 34 states including all NATO member states apart from Albania and Montenegro and a few non-aligned states (namely Bosnia-Hercegovina, Finland, Georgia, Sweden and Ukraine)[11].

Although, each country is entitled to fly over any other country within the limits of the quota system, the actual flight activity has developed in a less balanced way. NATO member states have agreed not to overfly each other. NATO states are concentrating their flights on the Russian Federation and Belarus, exploiting most of the passive quota of those countries (42). In return Russia performs 42 flights annually over NATO states including seven flights over the United States (in 2017). A smaller number of flights were performed in 2017 by non-aligned states: Ukraine (12), Sweden (6), Finland (2). Over the years the total number of active flight missions has been about one hundred annually. Several flights are performed as shared missions of two or three parties in order to reduce the cost per country[12].
Overall the flight activity reflects the politico-military tensions and security concerns between NATO states and the Russian Federation. It addresses such concerns by creating transparency within limits.

3. Disputes hampering full treaty implementation

The treaty opens the full territory of parties to observation flights with the exception of a 10 km zone along the border of non-parties. Since entry into force several impediments to full territorial accessibility have come up, two of them as a

[10] The certified camera configurations are designed for operation at different flight altitudes. Some countries operate camera configurations which allow observation below relatively low lying clouds: Canada and France (1210 m), Germany (1550 m, in preparation), Russian Federation (1130 m), Sweden (1830 m), Turkey (1790 m), USA (2150 m).
[11] The Czech Republic and Slovakia became parties after the dissolution of Czechoslovakia on 1 January 1993 as successor states.
[12] A full account of flight activity in 2008 can be found in (Spitzer, 2009).

consequence of unsolved status conflicts. The impediments occurred in the following time sequence[13].

2002-2016: No Access to some US islands

The Treaty covers both the continental United States as well as US island territories. Access to the Hawaiian Islands was opened in 2007. The Russian Federation has repeatedly asked for flight access also to several smaller islands in the Pacific and the Atlantic[14]. Only in 2016 the US submitted the necessary declarations for the remaining islands including Guam in the Pacific, which hosts a major military base. The first Russian flight over Puerto Rico and the US Virgin Islands was performed from 28 May to 3 June 2019 (OSCC, 2019). The impediment can be considered as resolved.

Since 2010: No flights in the Russian 10 km border zone of Abkhazia and South Ossetia

In consequence of the August 2008 war between Georgian, Russian and separatist forces, the Russian Federation had recognized the entities of Abkhazia and South Ossetia as independent states[15]. Georgia and all other Open Skies parties apart from Russia consider Abkhazia and South Ossetia still as part of Georgia's national territory – in spite of the de facto separation. Since May 2010 the Russian Federation has rejected flight plans of other parties which would have entered the 10 km zone along the border of Abkhazia. This rejection has been heavily criticized in the Open Skies Consultative Commission and by national capitals[16]. It is a classical dilemma of an unsolved status conflict. The practical effect on overhead image acquisition capability is small, because panorama cameras when flown high enough can view distances well over 10 km[17].

Since April 2012: Georgia refuses to accept overflights by Russia

On 4 April 2012 the head of the delegation of Georgia to the OSCC submitted a letter declaring that Georgia will no longer allow any observation flight that includes participation of the Russian Federation over the territory of Georgia (OSCC, 2012). The letter referred to the rejection of an US-Romanian flight plan of May 2010 which

[13] In addition there have been disputes over flight altitude restrictions which mandated high flight levels, e.g. over the Moscow area, over Chechnya, in Norway and Canada. Some of the cases are caused by different national standards and procedures for air traffic control.

[14] See e.g. (OSCC, 2015) for details..

[15] The entities of Abkhazia and South Ossetia had broken away from Georgia in two bloody secession wars (1991-94). The conflict had a complicated history concerning ethnic composition of the population and political affiliation. Both entities had an autonomous status in the USSR. For details see e.g. (Richter, 2019, pp.16-17) and sources quoted in (Spitzer, 2018). Today Abkhazia and South Ossetia are recognized by five UN member states only: Venezuela, Nicaragua, Nauru, the Russian Federation and Syria.

[16] E.g. the United States have determined in the 2018 Arms Control Report that Russia was in violation of the treaty by "refusing access of observation in a ten kilometer corridor along its border with the Georgian regions of South Ossetia and Abkhazia". (State, 2018)

[17] It should be also noted that parties refrained from extending their flights over Georgia to the break-away territories. The government of Georgia would not have been in a position to guarantee the safety of such flights.

would have entered the 10 km zone along the Russian border of Abkhazia. Georgia sees this rejection as a violation of the Open Skies Treaty and of international law.

Since March 2014: No flights over Crimea

The annexation of Crimea by the Russian Federation in March 2014 is seen by other parties as a violation of international law. In May 2014 the Russian Federation invited other parties to overfly Crimea as part of missions over Russia. Other parties have refrained from doing so because it would imply recognition of the annexation. Thus the major Russian naval base in Sevastopol is no longer observed by Open Skies flights. Again a regional status conflict is preventing full treaty implementation.

Since June 2014: Flight length restrictions over the oblast of Kaliningrad

On 10 June 2014 the Russian Federation notified all parties on a flight length restriction of 500 km over the oblast of Kaliningrad.(Open Skies, 2014) The oblast comprises an area of 15.125 square kilometers with a maximum East-West extension of about 170 km and a maximum North-South extension of about 100 km[18]. In detail, Russia designated the airport of Krabrovo in the Kaliningrad oblast as an airfield that can be used for Open Skies flights with a maximum distance of 500 km. In addition flights out of the Open Skies point of entry in Kubinka near Moscow have to observe a component part of maximum 500 km when flying over the oblast. Previously flights out of Kubinka had included longer observation distances over the oblast. Several parties protested in the Open Skies Consultative Commission[19]. They emphasized that the agreed maximum flight distance for flights out of Kubinka is 5500 km. According to the treaty each state party shall ensure effective observation of its entire territory. Maximum flight distances from Open Skies airfields have to be set and notified correspondingly.

The matter was disputed heavily since 2014 without reaching consensus. Observing parties have respected the limit in flight missions over Russia under protest. Russia has claimed, last time in the OSCC session of 20 May 2019,

"…that the maximum flight distance of 500 km enables an effective observation of the entire territory of the Kaliningrad region, obtaining images of up to 98 per cent of its territory from a single observation flight with the possibility of observing any of its points"[20].

In June 2017 the US administration formally accused Russia of violating the treaty by limiting the flight length over the oblast. In retaliation the US imposed limits on

[18] The oblast is a Russian exclave on the Baltic Sea surrounded by Poland and Lithuania. The formerly German territory was integrated in April 1946 into the Russian Soviet Federative Socialist Republic (SFSR), the predecessor of the present Russian Federation.

[19] The United States have determined in the 2018 Arms Control Report that Russia was in violation of the treaty by "imposing and enforcing a sublimit of 500 kilometers over the Kaliningrad Oblast for all flights originating out of Kubinka Open Skies Airfield". (State, 2018)

[20] In the view of the author a full observation of the area in one 500 km flight is only possible under rare conditions: Operating a panorama camera from 10 km altitude under a nearly cloud free sky. However it should be possible to photograph most military sites of known location in one flight of 500 km under favorable cloud conditions.

Russian flights over the Hawaiian Islands and closed some airfields for Russian overnight stops, still leaving the full US territory accessible to Russian observation. Russia responded by closing three Open Skies airfields for US flights[21].
The oblast is at the center of security concerns both of Russia and of NATO states, in particular the Baltic States and Poland. It hosts important military bases, a port of the Russian Baltic fleet as well as early warning radar stations and short range nuclear capable missiles. Of particular concern are the Iskander manoeuvrable missiles[22]. The system has been modified for launching also cruise missiles. According to (FAZ, 2019) Russia has expanded and modernized the storage capacities for nuclear weapons in the Kaliningrad region. Both the manoeuvrable rocket and the cruise missile version of the Iskander have a significant military capability due to their targeting accuracy and their manoeuvrability which makes detection and hits by missile defence harder.

4. Modernization of aircraft and sensors

4.1 New Open Skies aircraft

The above described impediments to full treaty implementation are real, but they are only part of the story. The core of the story is the fact that the major players, the US administration and the Russian leadership, as well as the governments of other parties are holding on to the Treaty for the time being in spite of compliance disputes. Major investments in modernization of Open Skies hardware have been made.

Russia was first, already in 2006, to provide a budget for two new long range Open Skies aircraft of type Tu 214. The first of those aircraft was displayed in August 2011 at an air show in Moscow (see figure 1). Open Skies has the attention of the top Russian leadership; President Putin took a tour of the aircraft. Both aircraft and the digital image sensors on board of type OSDCAM 4060 were certified for use in Open Skies (through the agreed inspection processes for equipment to be used under the treaty) in Kubinka in September 2018[23]. The cost of the modernization program was reported as 220 million USD at the 2010 Review Conference of the Treaty (Open Skies Review Conference, 2010).

[21] The restrictions were communicated by the US administration as an incentive for the Russian Federation to return to full treaty compliance. For details of the US measures see (State, 2018).
[22] In reaction to the deployment of US missile defense units in Poland, Russia deployed Iskander missiles in the oblast. The Iskander missile family is reported as comprising road-mobile manoeuvrable missiles with accurate strike potential down to a circular error probable of 5-7 meters. The Iskander can be tipped with several conventional warheads including a cluster munition warhead, a fuel-air explosive enhanced blast warhead, an earth penetrator for bunker busting and an electro-magnetic pulse device as well as with nuclear warheads (from Wikipedia.com, which quotes numerous sources, access 8 August 2019).
[23] The certification procedure was performed 2-11 September 2018. All attending parties apart from the US signed the certification document on 11 September. The US signature was submitted on 26 September in a session of the OSCC without giving reasons for the delay.

Fig. 1 A Russian Open Skies aircraft of type Tu 214 ON on display at the Moscow Air Show, August 2011 (courtesy: US Air Force)

Germany had modified a Russian made Tu 154 jet liner for Open Skies use in the years 1993-1995. The aircraft performed successful trial missions, but was lost in a mid-air collision over the Southern Atlantic in September 1997. It took eighteen years and a lot of lobbying before the German Parliament approved a budget for a new Open Skies aircraft in November 2015[24].

It was decided to acquire a little-flown corporate airliner of type Airbus A319 CJ. The aircraft model A319 CJ has four extra fuel tanks in the freight compartment to allow for long distance direct transit flights of over 6000 km. Thus Germany will be in a position to perform observation flights far beyond the Urals. The aircraft was adapted for its future role by Lufthansa Technik in Hamburg and by several subcontractors. It was handed over to the Bundeswehr on 21 June 2019. Figure 2 shows the aircraft at the Lufthansa base in Hamburg.

The aircraft will be available for up to 12 active German missions annually as well as for leasing by partner nations[25]. The target date for certification is fall 2020. Before this happens, extensive test flights have to be performed, in order to establish the flight altitude corridors in which the digital sensors yield the treaty mandated resolution. The cost of acquisition and retrofitting of the aircraft was around 120 million Euro, including cost for training flight crews.

[24] The decisive initiative came from several parliamentarians who questioned the government on providing a German Open Skies capability in 2012. One of the parliamentarians, a retired colonel of the Bundeswehr, succeeded in placing the objective in the coalition agreement of the Christian Democratic and Social Democratic Parties in November 2013. The deterioration of conventional arms control and the events of 2014 in Ukraine helped to enhance awareness and acceptance. For more details see (Müller, 2016).

[25] The aircraft has four working stations for sensor operators, 16 seats for inspectors of the observed party and for mission personnel of partner nations, as well as 25 extra seats.

Fig. 2 The new German Open Skies aircraft of type A 319 CJ (source: Lufthansa Technik)

The two existing Open Skies aircraft of the ***United States*** (modified Boeing 707 models) were built in the 1960's. Several recent missions had to be terminated early due to technical failures. The former Secretary of Defense, Mattis, decided to aim for parity of US Open Skies assets with Russia. In consequence a budget of 222 million USD was requested from US Congress and approved in the National Defense Authorization Act (NDAA) for Fiscal Year 2019. The bidding process for two long-range aircraft is under way.

Several parties use existing aircraft: Canada, France, Hungary, Romania, Sweden, Turkey and Ukraine as well as Russia (five medium range An-30 and one Tu 154). The aircraft of the Czech Republic and the UK have been put out of service. The Pod group was dissolved end of 2013. The sensor pod with film cameras is only flown on C130 aircraft of Canada and France. Bulgaria stopped flying their An-30 aircraft for Open Skies missions in 2019. Most other countries exploit their active flight quota by renting Open Skies aircraft from Hungary, Romania, Sweden and Ukraine or are sharing missions.

4.2 Open Skies sensors: Transition to the digital age

Under the rules of the treaty, Open Skies sensors have to be commercially available to all parties. When the treaty was negotiated between 1990 and 1992 the commercial market of aerial cameras was dominated by film cameras, mostly with

panchromatic (black and white) film. The treaty allows for framing cameras and (wide angle) panchromatic cameras with resolution no better than 30 cm[26].

The transition to commercial digital aerial cameras was initiated by the presentation of a large format mapping camera by the company Z/I Imaging (Oberkochen, Germany) in 2000. Today three digital camera formats are being used commercially: small format or consumer cameras with about 1-30 Megapixel (MP), medium format cameras weighing a few kg with about 40-150 MP and large format cameras with up to 450 MP.

The Open Skies Treaty authorizes the OSCC to decide on technological updates of existing sensor categories without having to go through a formal amendment (re-ratification process). How to store and transmit information digitally has been addressed in Open Skies already in 1994, primarily in connection with the readout of video sensors, which are a treaty sensor category (with resolution no better than 30 cm). Intensive work to introduce digital aerial cameras started in 2006 in the Informal Group of Sensors of the OSCC.

It took many tests and demonstrations of certification procedures until the OSCC could decide on the introduction of digital cameras in the treaty category of video sensors. Availability on the commercial market was checked in 2008. Cameras with four spectral channels for blue (B), green (G), red (R) and near-infrared light (NIR, with wavelength between 0,69 and 1,1 micrometers) can be used, also a panchromatic channel. Today, certification of sensors is based on a sequence of five steps: (i) lengthy flight tests of the certifying party in order to establish the flight altitudes at treaty resolution for the various camera configurations; (ii) submission of extensive documentation on sensors and processing software, as well as on the outcome of test flights, (iii) demonstration of certification procedures to state parties (the precertification event), (iv) intermediate meeting in order to resolve remaining questions, (v) the actual certification event which demonstrates and confirms the flight altitudes for treaty mandated resolution.

Further work was needed in order to agree on a verified data processing chain. This comprises (a) processing of raw image data to composite images in an agreed Open Skies image data format, (b) duplication of image data, (c) duplication verification, (e) erasure of raw data after processing, and (f) erasure verification.

How is cheating prevented? Inspectors of the observed state are on-board during data taking. They check that the certified flight altitude for 30 cm resolution is observed. At the end of a mission the digital storage devices are sealed for transport into the media processing station. Image processing, duplication and erasure of raw data is performed in a controlled way in presence of inspectors and experts of both sides. Checks of data and erasure fidelity are being made. The software has to be documented for all parties.

[26] The resolution is determined on bar targets of black and white bars. The resolution definition which was adopted by the OSCC implies that 30 cm resolution of a film camera under Open Skies corresponds roughly to the ground resolution which is usually quoted for digital cameras: i.e. the size of a ground area which is imaged by a picture element (pixel) of a digital camera. For details see (Dunay et al., 2004, p. 43 and p. 74).

As a result the image duplicates which are handed over to the observing and the observed party have a very high degree of authenticity[27]. For details see (Orych, 2015). Thus Open Skies images can be used in bilateral disputes as a source.

4.3 A system with forty lenses: The Russian OSDCAM 4060

Russia was the first party to present a digital camera system for certification in 2013. The system had been developed by a small Russian company KSI in Moscow using sensor chips and lenses available on the commercial market of consumer cameras. The system consists of forty small cameras which are configured in four subsets which have the same focal length each: Six cameras for data taking at low altitudes (1050-1130 m), 18 for medium altitudes (3230-3500 m) and ten for high altitudes (6490-6790 m). All cameras operate as RGB cameras[28]. The ground swath covered ranges from 2740-2940 m at low altitudes to (7750-8077 m) at medium altitudes and 11.680-12.430 m at high altitudes[29]. There is also a camera subset which operates in the NIR at altitudes of 1390-1440 m.
Each subset produces a strip image which widens at larger observation angles. The strip images can be composed to a composite image. Fig. 3 shows the lens configuration of the system.

[27] Providers of commercial satellite imagery have confirmed that the degree of authenticity of Open Skies imagery is unmatched in the satellite world. Transmission and processing of commercial satellite image data is done only by one party without outside checks and without disclosing their internal proprietary methodologies. (VERTIC, 2017)

[28] Aerial RGB cameras have – similar to consumer cameras – an array of filters which are transparent for red, green or blue light, over the matrix of light sensitive sensor elements.

[29] The camera system is certified for use on three aircraft types: An-30, Tu 154 and Tu 214. The ranges of flight altitudes for 30 cm resolution and the related ground coverage, which are quoted in the text, comprise the performance on all three aircraft types. The certified values for An-30 and Tu 154 aircraft are given in (OSCC, 2017).

Fig.3. The Russian Open Skies camera system OSDCAM 4060 (source: www.poksi.ru/files/OSDCAM 44060-Eng.pdf, access 12 August 2019).

The camera system was first flown in an Open Skies mission in July 2014 after an eight month delay by the US administration in signing the certification document[30].

4.4 The digital sensors system DVIS of the United States

The US had been a vocal proponent of going digital in the IWGS and at Open Skies Review Conferences since 2005. The slogan of the US chairman of the IWGS was “faster, cheaper, better”. Creating a budget for acquisition of digital sensors turned out to be tedious due to bureaucratic drag and competing priorities for defense acquisitions. A decisive step was taken in March 2012 by the Presidential Policy Directive 15. The directive tasked the Department of Defense to establish a budget for acquisition of digital sensors for the two existing US Open Skies aircraft.
The budget was approved by Congress in steps (2013 and in subsequent years). The request for proposals was released in September 2015. It contained quite challenging ground coverage specifications which were derived from the ground coverage of the existing film cameras (one vertical and two oblique framing cameras and one panoramic camera)[31]. The contract was awarded in February 2016 to the veteran-owned company KIHOMAC (KIHOMAC, 2016) with a volume of 37 million USD.

[30] This delay was caused by interventions of agencies within the US administration which were suspicions of the information gathering potential of the new camera. In the end the forces won which successfully argued that 30 cm from a digital device is equivalent to 30 cm from an analogue device (film) in Open Skies. However, the RGB capability and the digital accessibility of the images provide an added value which all parties can exploit after going digital.
[31] The ground coverage of the US film cameras vary from ca. 3000 m from a vertical framing camera flown at an altitude of ca. 2000 m to 12.500-23.200 m for a panoramic camera flown at 10.800 m according to (OSCC, 2017).

The designers of KIHOMAC took an approach which has some similarity to the Russian approach: Using arrays of multiple cameras to obtain ground coverage of about 99 degrees from three different altitude levels. They decided to combine medium format cameras of type CM-MK produced in Canada by the US owned company Teledyne Optech with 84 MP (10720 x 8064 pixels at 6 micrometers size each). The camera is employed in three spectral variants: (a) as RGB camera, (b) as pan-chromatic camera and (c) as camera operating in the NIR. The high altitude configuration consists of five panchromatic and five RGB sensors covering a ground swath of 18,9 km from an altitude corridor of 7600-8500 m. The medium altitude configuration uses five RGB cameras covering a ground swath of 14,3 km from altitudes 5800-6400 m. The low altitude configuration has four individual sensors filtered to Red, Green, Blue and NIR and a ground swath of 3100 m from altitudes 1200-1500 m. Image processing will take several days – longer than the present film development[32].
Delays in tests of the system after delivery have been caused by the complexity of the design. Certification is expected in fall 2020 or spring 2021.

4.5 The digital sensors on the German Open Skies aircraft

Germany – similar to the US and Russia – acquired a system of electro-optical sensors which take images in three altitude corridors. In contrast to Russia and the US the German system will have both RGB and NIR cameras at all three altitudes[33]. In addition Germany is the first party to operate a thermal infrared camera system[34].
The RGB and NIR cameras employ the model PhaseOne iXU-RS 1000 from the Danish company PhaseOne with lenses of different focal length from 23 to 90 mm. The camera has 100 MP (11608 x 8708 pixels of size 4,6 micrometer).
The low altitude configuration comprises one vertically mounted RGB and one NIR camera. It is expected to cover a ground swath of 3500 m across track from an altitude of 1550 m. The medium altitude configuration consists of two slightly tilted (by 5 degrees) RGB and NIR cameras each, providing a resolution of 30-35 cm over a swath of 5660 m from an altitude of 3580 m. The high altitude configuration

[32] Development of photographic film from Open Skies flights can be usually done overnight. The data from the multiple cameras for medium and high altitudes of the US system have to be stitched together in order to yield three images each, one for vertical view and two for oblique view. This operation is time consuming.
[33] Near-infrared cameras support the monitoring of the health of vegetation and the discrimination of different types of vegetation (e.g. the discrimination of conifers from deciduous trees). This can be used, for example, to detect and analyse camouflage on vehicles, when such camouflage is made of cut vegetation which is dead or dying. Near infrared imaging has been also used for environmental reconnaissance, for example, by estimating the size of expected crops.
[34] Thermal infrared radiation is emitted by all objects day and night due to their surface temperature. Thermal sensors were included in the treaty sensor set to support data taking at night and during winter in northern regions when illumination by sunlight is short and faint. The resolution limit of 50 cm was seen in 1992 as a compromise between the resolution of optical cameras and the performance of then available commercial infrared sensors at flight altitudes of about 1000 m (Hartmann, Heydrich, 2000, p. 62). An object can be recognized on a thermal IR image by shape if its temperature is different from the temperature of the surrounding area.

comprises three RGB and NIR cameras, each providing a resolution of 30-35 cm over 90% of the full swath (10 090 m) from an altitude of 5870 m (IGI, 2019).
The thermal system consists of two tilted uncooled microbolometer cameras with 1024x768 pixels each of size 17 micrometer[35]. The images of the dual camera will be processed into one continuous image with a resolution of 90-130 cm over a ground swath of 1900 m when operated at an altitude of 1550 m.
The sensors are mounted on gyro-stabilized mounts, one for the sensors of each altitude and one for the thermal sensors. Two of the mounts are placed in a front freight department of the aircraft, two of them in the rear, each pointing at windows of 28 mm thickness which are transparent for visible and NIR light, or thermal radiation, respectively. Thus Germany will have the most comprehensive imaging capability concerning spectral performance, by providing images from RGB, NIR and thermal radiation[36]. The US system will be superior in ground coverage from medium and high altitudes.

4.6 Romania: A fast late comer

Romania is operating AN-30 medium range turboprop aircraft equipped with one mapping film camera Wild Aviophot RC-20. In 2018 it was decided to provide a modest budget for acquisition of digital sensors. Romania asked for offers of a compact system of cameras on one gyro-stabilized mount, which can provide images at treaty resolution from three altitudes. Romania placed the order with the small German company GGS (GGS, 2019).
GGS delivered and installed medium format cameras from PhaseOne in spring 2019. The low altitude configuration consists of one RGB and one NIR camera each of type iXM-RS100 (11.608 x 8.708 pixels of 4,6 micrometer size), providing 30 cm resolution over a swath of 3480 m from an altitude of 1500 m. The medium altitude configuration comprises one vertically mounted RGB camera and one NIR camera each of type iXM-RS-150 (14.204x10.652 pixels of size 3,76 micrometer), which provide 30 cm resolution over a ground swath of 4260 m, when flown at 3190 m altitude. Two obliquely oriented RGB cameras cover side strips up to ca. 6000 m on each side at resolution between 30 and 82 cm. The high altitude configuration comprises one PhaseOne RGB and NIR camera, each, of model iXM-RS150. The ground swath covered is 4620 m from an altitude of 5590 m.
Thus Romania is expected to operate a robust system, which works at three altitude levels both in RGB and NIR.

[35] Microbolometers are thermoelectric sensors operating a wavelengths in the region of 7,5-14 micrometer. Incoming thermal radiation heats a sensor element. The heat signal is subsequently transformed into an electric signal.
[36] The thermal camera system can only be certified once the OSCC has agreed on a revised certification procedure for cameras of present day technology. A previous decision on certification procedures for line scanner technology is no longer in force.

5. Outcome: Contributions to transparency and arms control verification

5.1 Creating transparency

The role and the outcome of Open Skies implementation are manifold, depending on the national interests and concerns of parties. Originally, as stated in the Preamble, it had a rather general scope of intentions and objectives:

"…Welcoming the historic events in Europe which have transformed the security situation from Vancouver to Vladivostok,

Wishing to contribute to the further development and strengthening of peace stability and co-operative security in that area by the creation of an Open Skies regime for aerial observation,

Recognizing the potential contribution which an aerial observation regime of this type could make to security and stability in other regions as well,

Noting the possibility of employing such a regime to improve openness and transparency, to facilitate the monitoring of compliance with existing or future arms control agreements and to strengthen the capacity for conflict prevention and crisis management in the framework of the Conference on Security and Co-operation in Europe and in other relevant international institutions…"

The treaty articles were more specific on the character of the aerial observation: Unlimited territorial access and cooperative execution of flights. The achievable transparency was purposely restricted in a twofold way:

(a) The verified resolution limit of 30 cm enables the detection of major military land vehicles and infrastructure, but excludes detailed reconnaissance, like recognizing the antenna of a tank.

(b) The flights contain only a limited surprise element. The time period between disclosure of the flight plan of the observing party and the beginning of the actual observation flight is about 24 hours, leaving enough time to cover sensitive equipment.

In addition, unfavourable weather conditions like very low lying clouds can prevent observation.

Still everything in the open remains visible if cloud levels can be under flown. This includes land vehicles, aircraft, ships and submarines in ports, missile sites, as well as all kinds of static military and civilian infrastructure.

How does Open Skies observation compare with satellite monitoring? (a) The resolution of Open Skies images for RGB or NIR light of 30 cm is comparable but not superior to the images of the most advanced commercial satellites Worldview 3 and 4 of Digital Globe, USA. Still, smaller countries prefer the access to Open Skies observation over commercial satellite imagery because of operation flexibility and cost. 30-50 military sites can be photographed in one flight mission at a cost below the acquisition cost of 30-50 satellite images[37]. (b) The resolution of Open Skies

[37] Procuring high resolution satellite images in a short time frame can be particularly expensive. The cost per scene can be up to several thousand USD. Germany is renting the Swedish Open Skies aircraft at a cost of ca. 50

thermal infrared images is far better than the resolution which can be obtained from commercial satellites cruising in 700 km orbits. For instance, the LANDSAT satellites offer a resolution of only 60 m in the thermal infrared region (wave length 7,5-14 micron). (c) A decisive advantage of Open Skies images is, as argued above, their verified provenance and their high degree of authenticity.

5.2 Contributions to arms control verification

Open Skies contributes to the verification of several arms control treaties:

(i) Open Skies images have been used to prepare and to complement on-site inspections under the CFE treaty. After the Russian suspension of CFE implementation Open Skies flights can be used to monitor the sites of conventional forces in Russia.

(ii) Open Skies flights have been used to photograph chemical weapon storage and destruction sites.

(iii) Open Skies flights are being used to monitor nuclear weapon and missile sites. A protocol to the New START Treaty includes Open Skies assets as monitoring tools.

5.3 Cooperation with the OSCE

All Open Skies State parties are participating in the OSCE. The relation of the treaty and its parties to the OSCE can be discussed on four levels: (i) Services provided by the OSCE secretariat, (ii) Shared national and OSCE resources, (ii) Cooperation in conflict prevention as specified in the treaty, (iv) Options for further cooperation.

(i) *Services provided by the OSCE secretariat.* Beginning with the main negotiation phase of September 1991 to March 1992 the secretariat of the OSCE (then CSCE, Conference on Security and Cooperation in Europe) has provided paid services to the Open Skies state parties. This includes meeting rooms in the Vienna Hofburg, administrative support and website management of an Open Skies delegate's website. The Open Skies website is handled within the OSCE delweb-website which is accessible to delegates who are nominated by Open Skies states, resp. by participating states of the OSCE.

(ii) *Shared national and OSCE resources*. Politically the Open Skies state parties and the bodies of OSCE operate independently. There exist shared information channels. The ambassadors and military advisors assigned to the OSCE in Vienna represent their country also in the OSCC. They provide consistency of national policies for all three OSCE dimensions and for non-OSCE arms control regimes and security building measures. Open

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000 Euro per flight (without salaries of the German team). This sum is below the cost of 30-50 high resolution satellite images. (German Verification Center, 2019)

Skies state parties make use of the OSCE Communications network, e.g. notably for Open Skies notifications. Delegates of all 57 OSCE participating states have access via the delweb to the text of OSCC decisions and to statements made in the OSCC which are documented in written form in the Journal of the OSCC. Access to documentation of Open Skies implementation is limited to representatives of Open Skies state parties.

(iii) *Cooperation in conflict prevention and crisis management.* The preamble of the treaty calls for strengthening the capacity for conflict prevention and crisis management in the framework of the CSCE (now OSCE). A procedural architecture for eventual implementation of this option has been specified in Annex L, Sec III, 1. of the treaty (OSCE, 1992, p.95):

'The Open Skies Consultative Commission shall consider requests from the bodies of the Conference on Security and Co-operation in Europe authorized to deal with respect to conflict prevention and crisis management and from other relevant international organizations to facilitate the organization and conduct of extraordinary observation flights over the territory of a State Party with its consent.'

This procedure has never been negotiated and executed. But it is worth being explored.[38]

Recommendation: The author suggests exploring need and feasibility of such flights, both in the OSCC and jointly with the head of the Conflict Prevention Center (CPC) of OSCE. Questions to be explored include:

- What kind of non-treaty missions are states parties willing to support with Open Skies assets?
- Are parties prepared to give the CPC a coordinating role in planning flights and data taking as well as in distribution and analysis of images taken?
- Who bears the cost of such flights and data processing of images?

A demonstration flight for testing proposed procedures would be helpful. It should be noted that Open Skies parties have considerable experience in shared missions and joint test flights.

(iv) *Options for further cooperation*. Could Open Skies images or insights from such images be made accessible to bodies of the OSCE, like the CPC? In general not. Open Skies images are government-official (confidential) among the Open Skies state parties and not accessible beyond. However, parties can use their insights and concerns from analysis of Open Skies images in informal bilateral or multilateral contacts in Vienna.

[38] A representative of Sweden has pointed out at the Open Skies Review Conference of 2010 that the option had been already proposed within the OSCE. The OSCE document "Stabilizing Measures for Localized Crisis Situations" proposes an aerial observation regime aimed at checking compliance with agreed stabilizing measures and building confidence and the possibility of using the procedures and measures of Open Skies. (Open Skies Review Conference, 2010 a).

6. Conclusion

The Open Skies Treaty has withstood the test of time in spite of implementation deficits. The value assigned to the treaty in the literature depends a lot on the perspective. The US expert Michael Krepon emphasized the symbolic relevance of opening the full territory to aerial observation:
"The point of the treaty has always been about symbolism rather than technical data collection". (Krepon, 2018).
An expert brief from the US Council on Foreign Relations argues:
"The Treaty does provide a valuable benefit: It serves as a tool to measure the health of US-Russian relations. Unlike arms treaties and agreements, Open Skies focuses an access and transparency, which are important ingredients for any good relationship between nations. The treaty provides preapproved implementation standards and guidelines for specific operational elements, such as flight routes, altitudes, and timing. These are quantifiable and measurable." (Reynolds, 2017)

The treaty has survived on the one hand because the US and the Russian Federation are backing it, most visibly through their investment in new aircraft. On the other hand, being a multilateral treaty there exist a range of diverse motivations and interests of parties to adhere to the treaty. States in neighbourhood of the Russian Federation, which lack satellite capabilities of their own, are clearly interested in the technical image data collection. These states include the Baltic States, Finland, Norway, Poland, Romania, Sweden, Turkey and the Ukraine. Interestingly, whereas Ukraine did not undertake observation flights in Russia before 2014, it does so since 2015 as shared flights with other parties. The military forces in the oblast of Kaliningrad are of particular concern for the Baltic States and Poland. Canada is an arctic neighbour of the Russian Federation.
France, Germany, Italy and the UK value Open Skies images as complement to their satellite reconnaissance capabilities but also for the confidence building effect. All parties acknowledge the value of cooperation of their mission personnel on-board and on the ground.

The treaty has a sound architecture and includes options for modernization. The elements of cooperation inspire those who work with the treaty. The built-in checks prevent cheating and guarantee the production of trustworthy images with a high degree of authenticity. However, the military relationship between the Russian Federation on the one hand and many (though not all) of the other parties on the other is characterized by mistrust and antagonism. This is despite cooperation in other fields like civil use of space assets, basic research and commerce. In the military field both sides, the Russian Federation and the US as well as France and the UK, are hostages of the other's nuclear potential. It is a metastable situation. Open Skies can contribute to stabilization in some way, but it is endangered should further escalation occur.

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